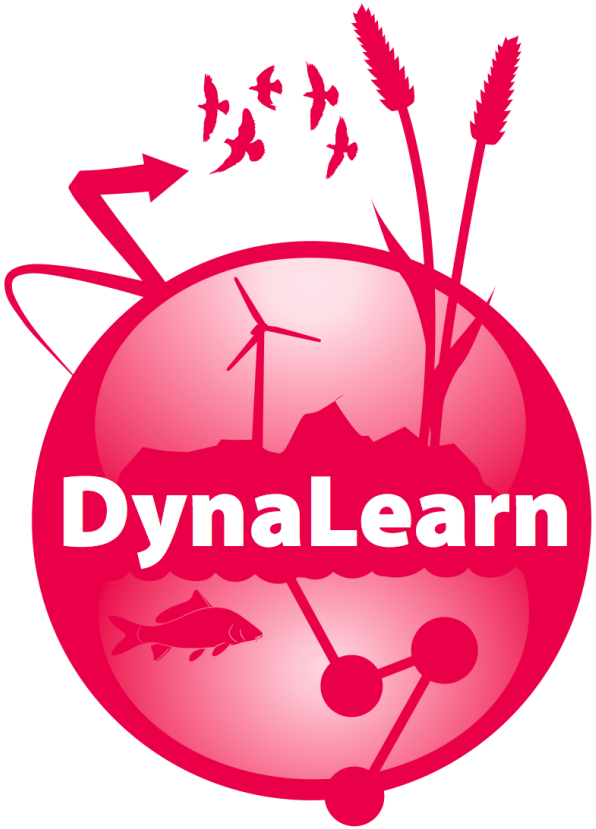


DynaLearn: The Qualitative Reasoning perspective

Bert Bredeweg

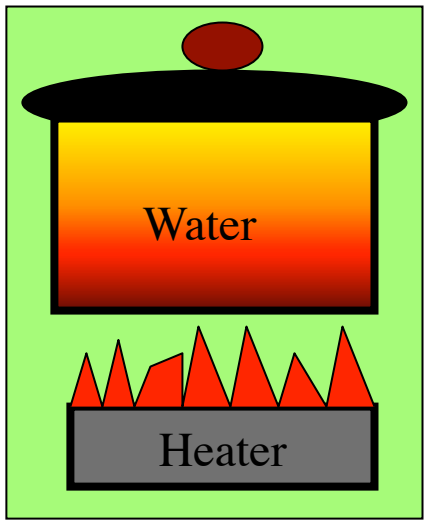
Informatics Institute, Faculty of Science
University of Amsterdam, Netherlands

This work is co-funded by the EC within FP7, Project no. 231526, http://www.DynaLearn.eu

Overview

- Problem statement and Context
- Qualitative Reasoning
  - Example
  - Inequality reasoning
  - Causal model (directions of change)
  - Finding & Ordering terminations
- Further main ideas from DynaLearn
- Concluding remarks

What happens? Why?



The water temperature and pressure increase

The water starts boiling, steam is generated

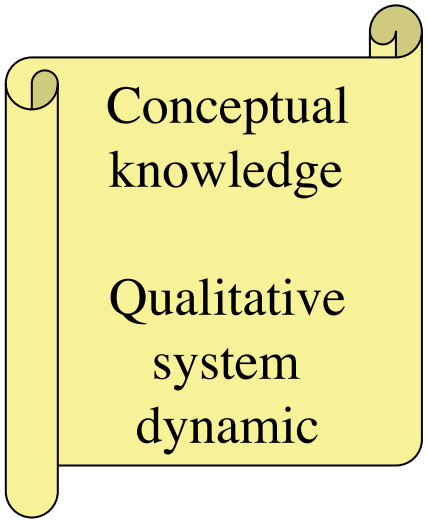
All the water has turned to steam

The boiler explodes, because the internal substance pressure is too high

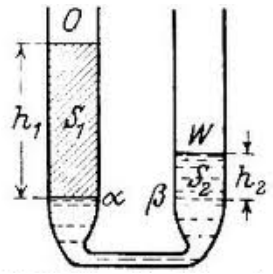
The substance temperature and the temperature of the heater become equal

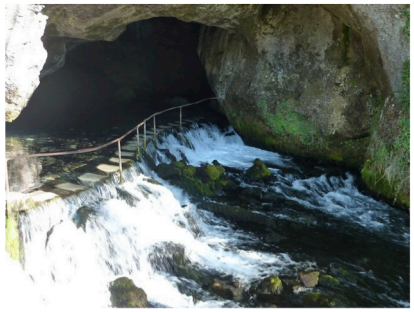
General characteristics

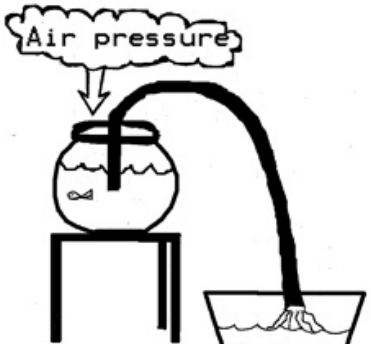
- Time / Changing behaviour
- Causality (cause-effect reasoning)
- No numbers (qualitative)
  - Landmarks / critical values
- From ‘structure’ to ‘behaviour’
- Often multiple ‘solutions’ (qualitatively distinct)
  - State-graph with multiple behaviour paths
- Assumptions / Perspectives
- General knowledge / First principles

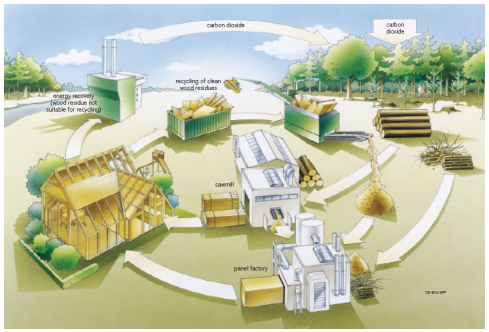


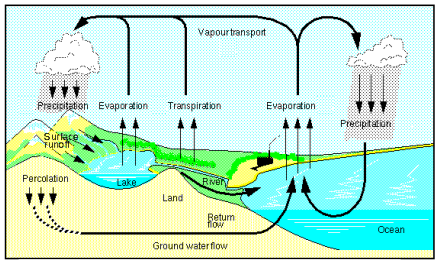
What happens and Why?











The Princeton Review AP Environmental Science Test (Q32)

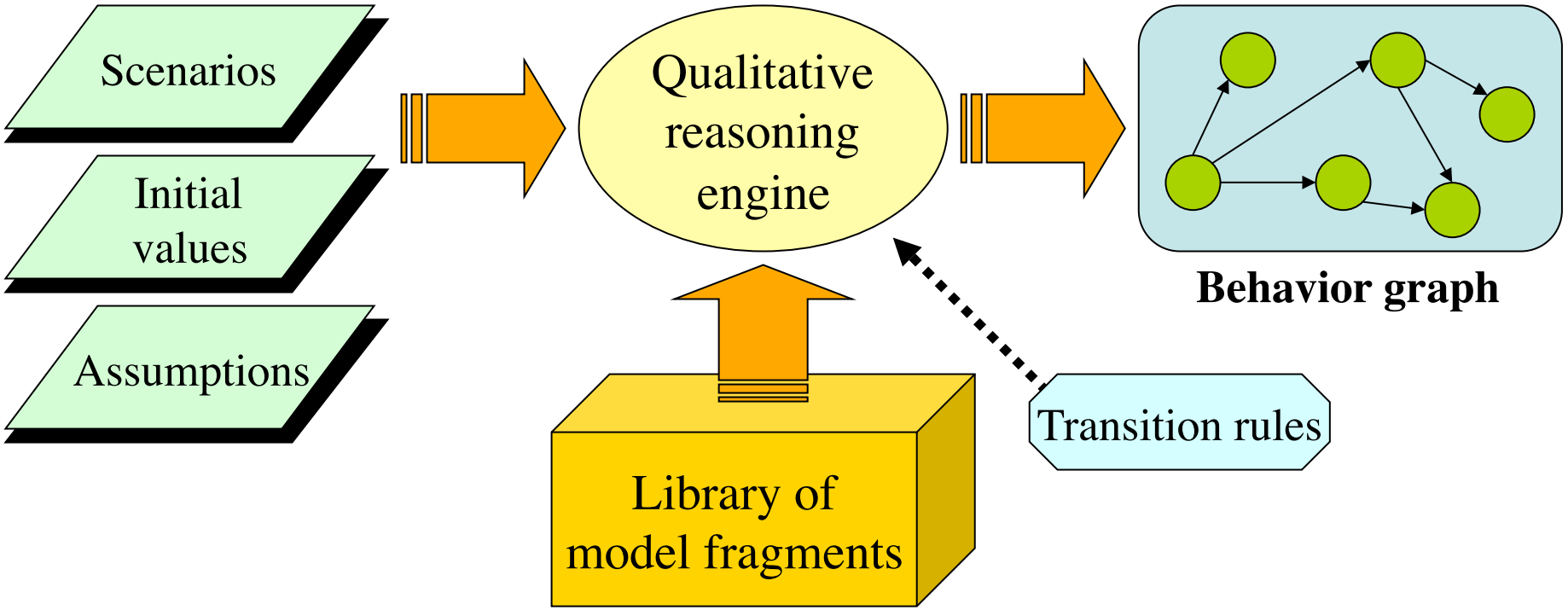
2007

32. Which of the following organisms is the first to be adversely affected by thermal pollution in a stream?

(A) Trees along the bank
(B) Insect larvae in the water
(C) Large fish migrating up stream
(D) Birds drinking the water
(E) Bacteria in the water

Qualitative Reasoning Engine

26th Int. Workshop: Playa Vista, CA, USA, July 16-18, 2012
- Multiple domains (e.g. Physics, Ecology, Economics, ..)
- Multiple tasks (Education, Device diagnosis, Robotics navigation, ..)

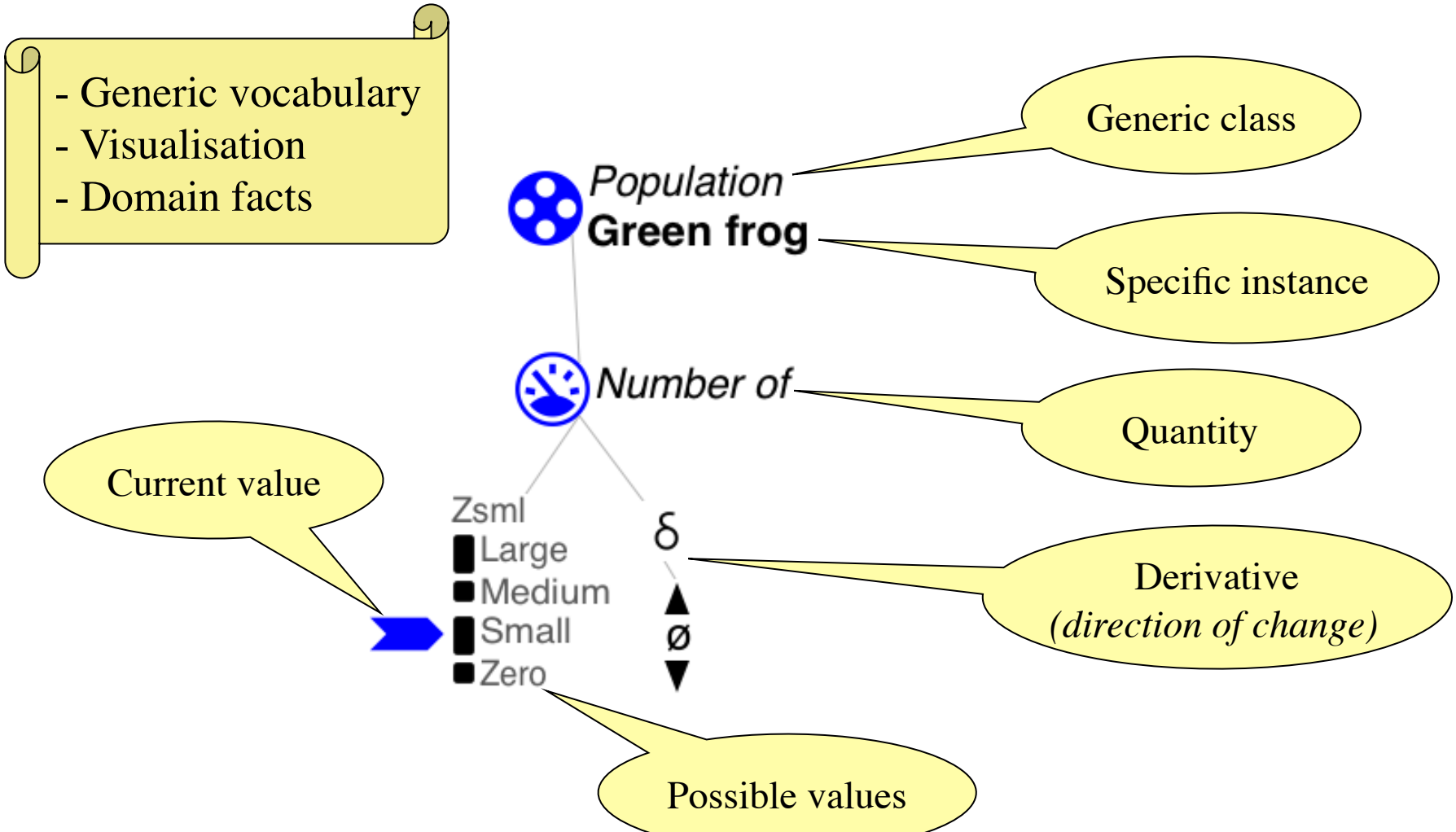


Example: Population dynamics

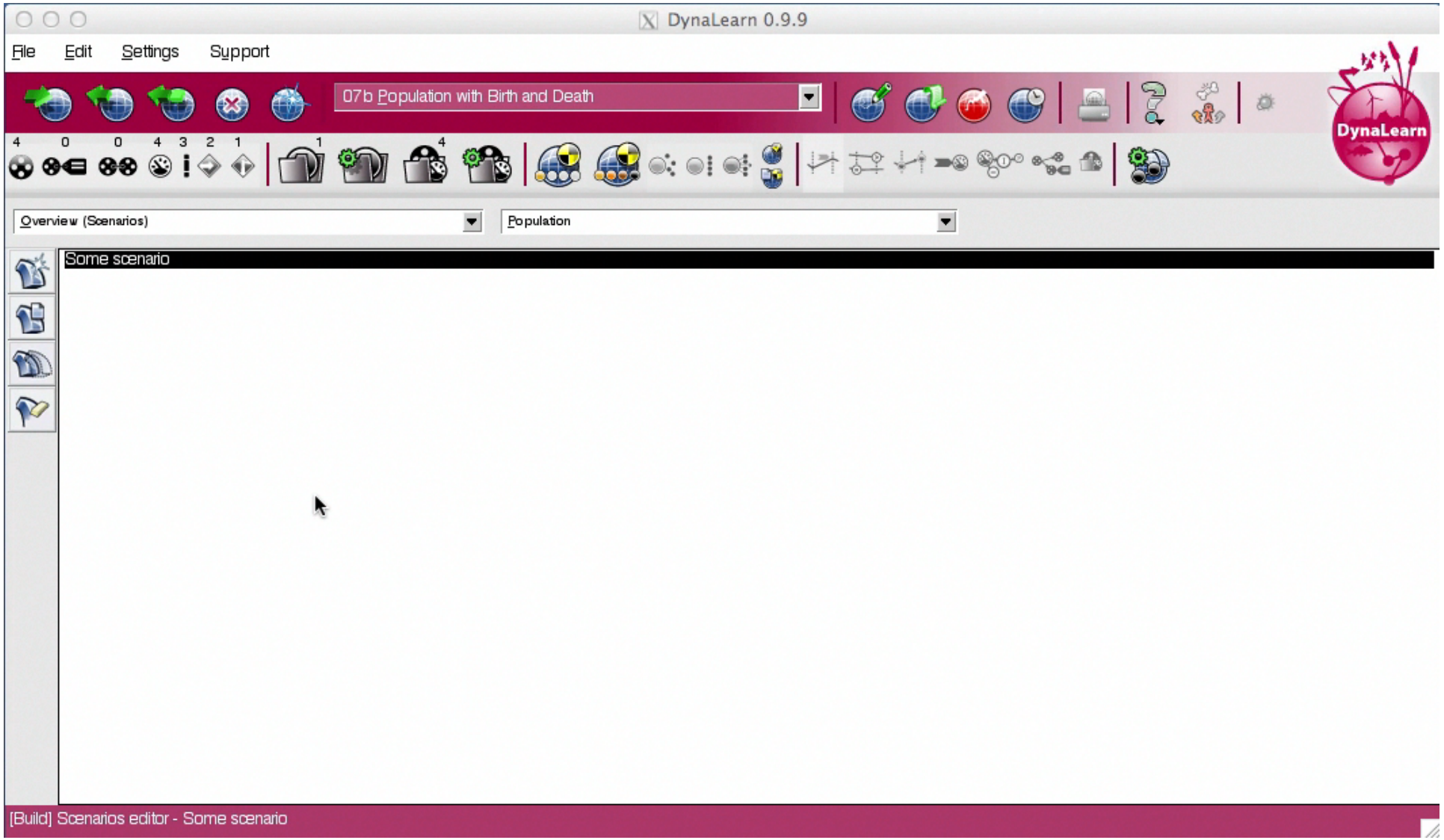
- How do populations in general behave?
- What processes determine their behaviour?

- *Issues:*
  - Size *(number of individuals)*
  - Birth / Natality
  - Death / Mortality

Scenario *(Starting situation)*



Demo – Modelling & Simulation



NaturNet-Redime

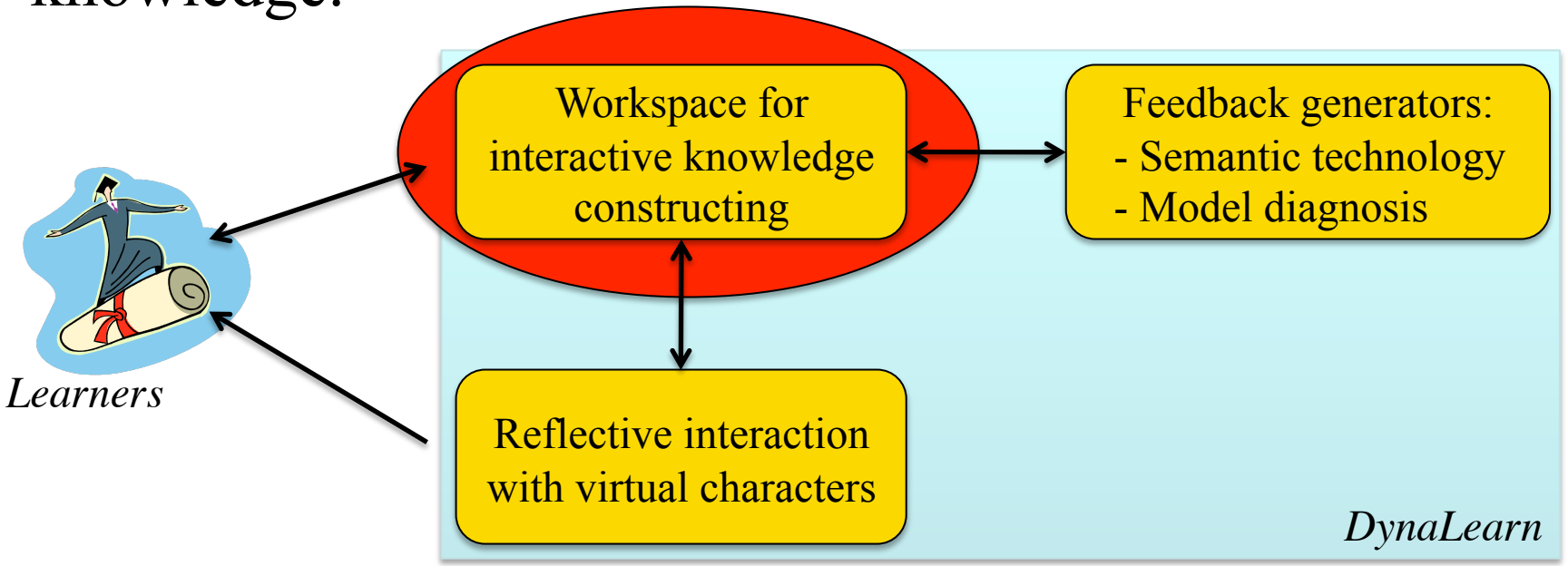
http://www.garp3.org

Garp 3

Special issue:
Ecological informatics, 4(5-6), 2009

DynaLearn - Main objective

- To develop an interactive learning environment that allows learners to construct their *conceptual* system knowledge.



- Applied to (environmental) science education
- Secondary & Higher education

Integrate proven technology

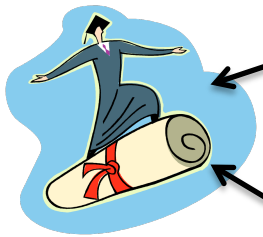
DynaLearn - Main objective

Accommodate the ***true nature*** of conceptual knowledge

React to the ***individual*** knowledge needs of learners

Workspace for interactive knowledge constructing

Feedback generators:
- Semantic technology
- Model diagnosis



Learners

Reflective interaction with virtual characters

Be ***engaging*** by using personified agent technology

- Applied to (environmental) science education
- Secondary & Higher education

Overview

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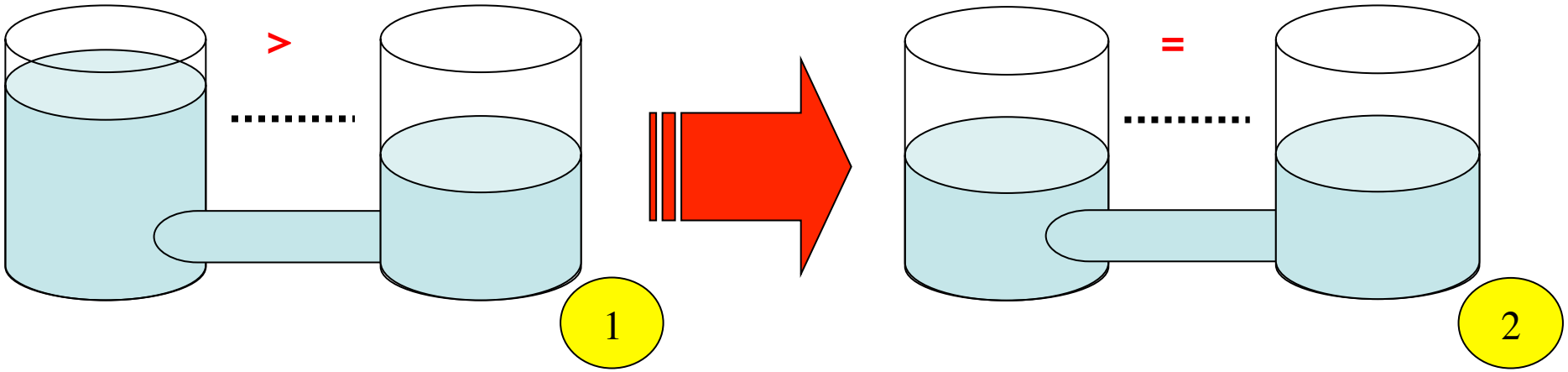
Communicating vessels

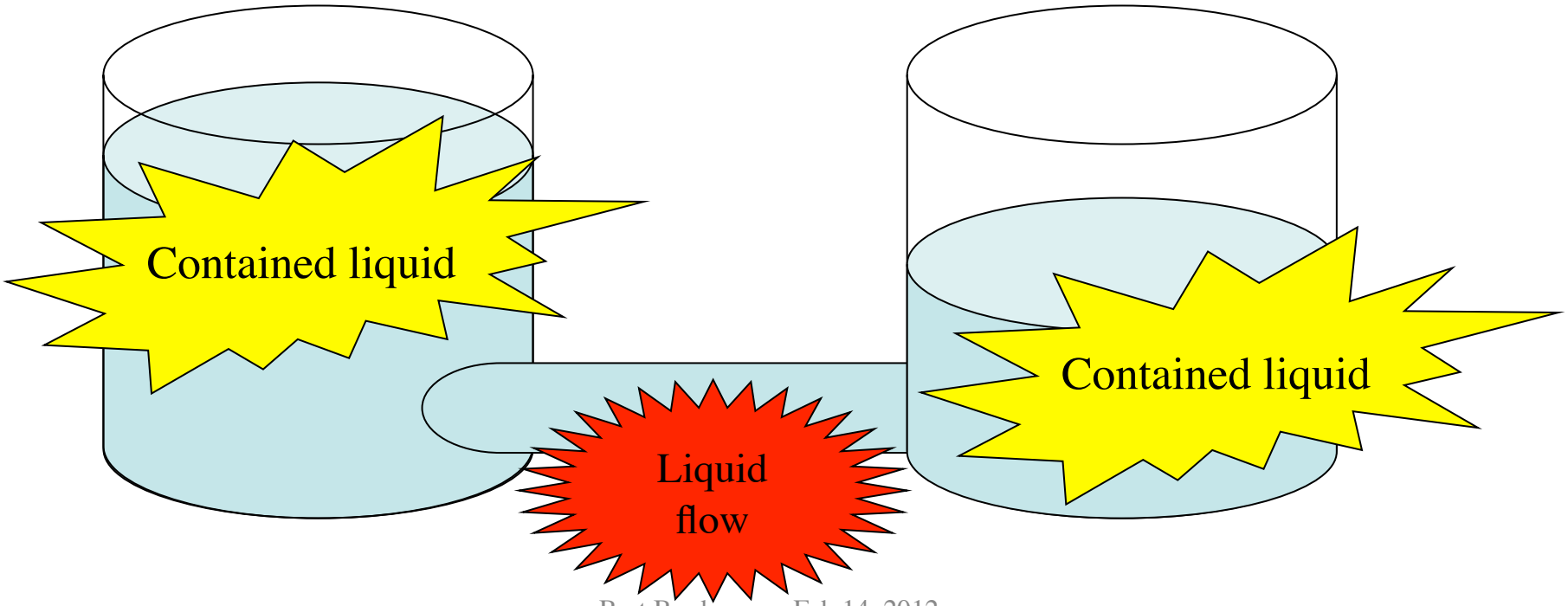


A QR model captures the knowledge that *explains* the system's behaviour
(a human interpretation of reality)

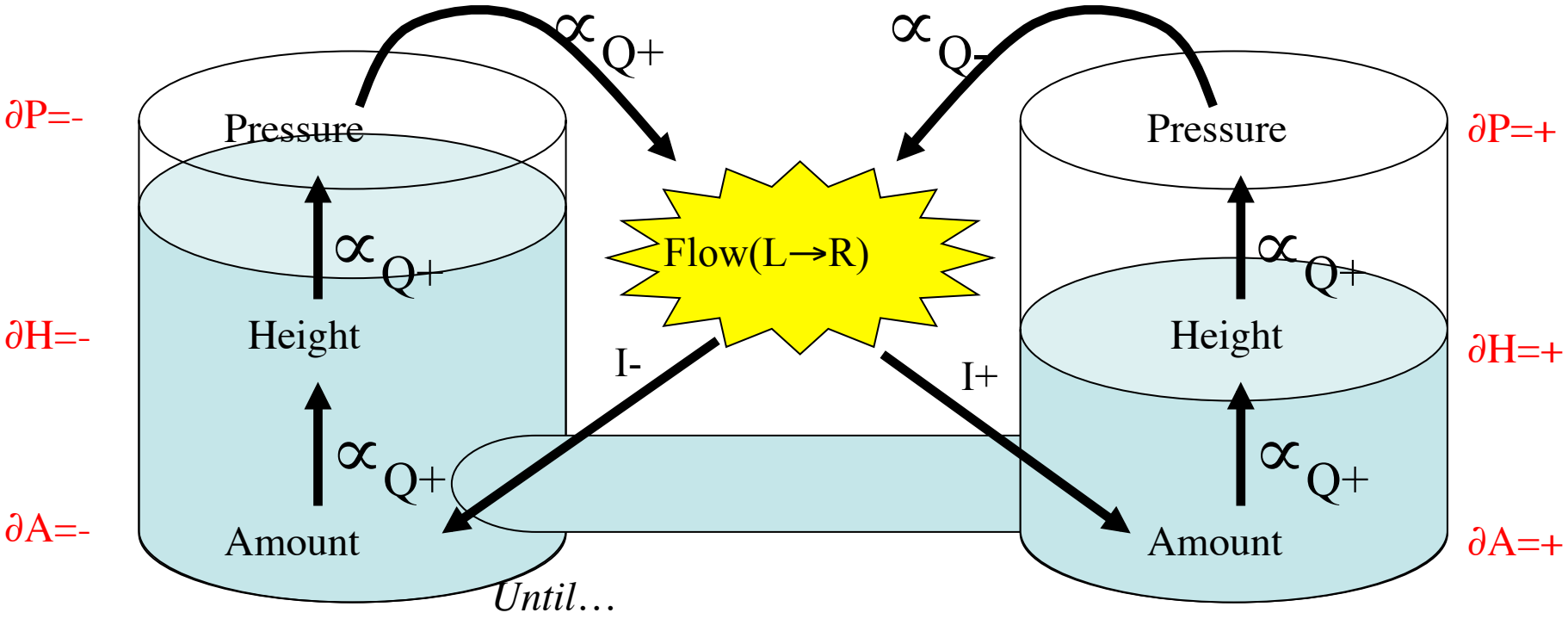
Model fragments

- Static (view)
- Process (cause of change)

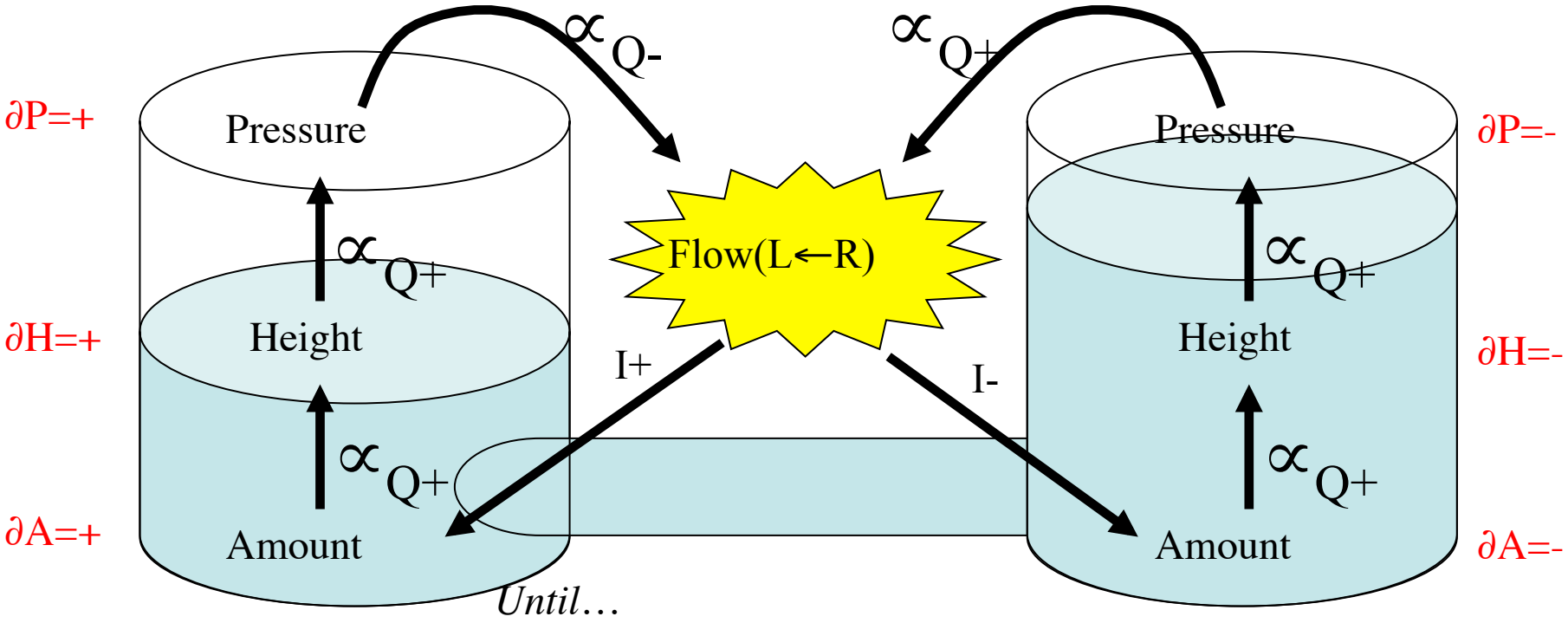
Knowledge chunks capturing 'First principles'



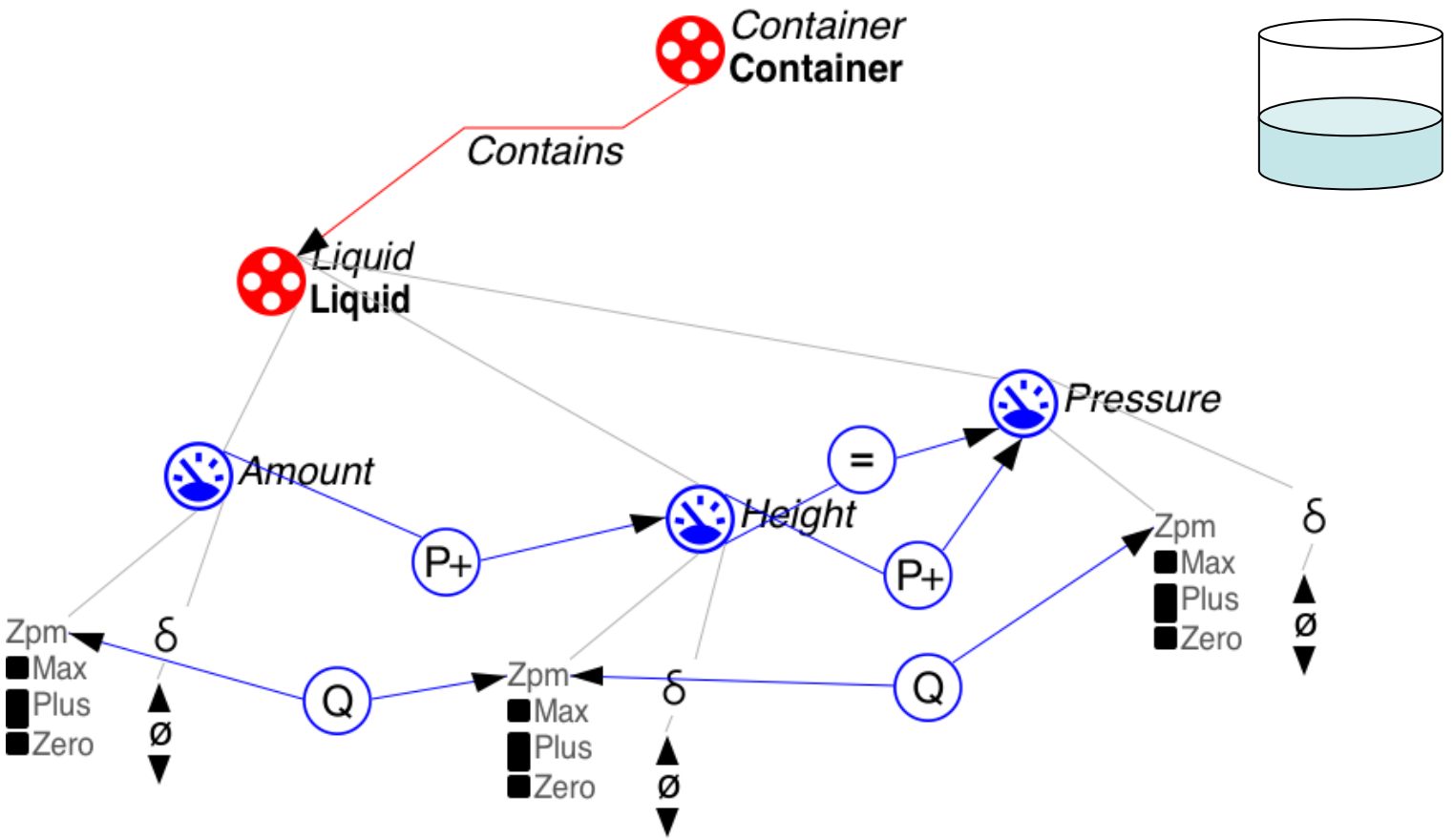
Explaining the behaviour (1)



Explaining the behaviour (2)



Static MF: Contained liquid

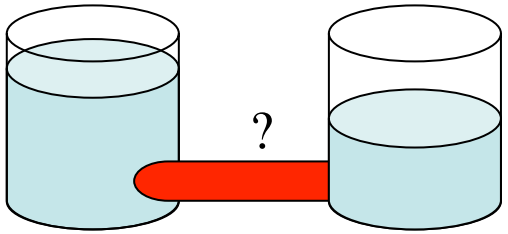


Processes

- Name and Type
- Collection of entities (partial system structure)
- Quantities involved
- Start (triggering) conditions
- Effects (what does it change)
- Stop (ending) conditions

Process MF: Liquid flow

- Name and Type: Liquid flow
- 'Entities': 2 contained liquids connected by pipe
- Quantities involved
  - Flow (F): {Min, Zero, Plus}
  - Pressure (P): {0, Plus, Max}
  - Amount (A): {0, Plus, Max}
- Start (triggering) conditions
  - Pressure LHS ≠Pressure RHS
- Effects (what does it change)
  - IF F=<+,?> THEN A_{LHS}=<?,–> and A_{RHS}=<?,+>
  - IF F=<0,?> THEN A_{LHS}=<?,0> and A_{RHS}=<?,0>
  - IF F=<–,?> THEN A_{LHS}=<?,+> and A_{RHS}=<?,–>
- Stop (ending) conditions
  - Pressure LHS = Pressure RHS

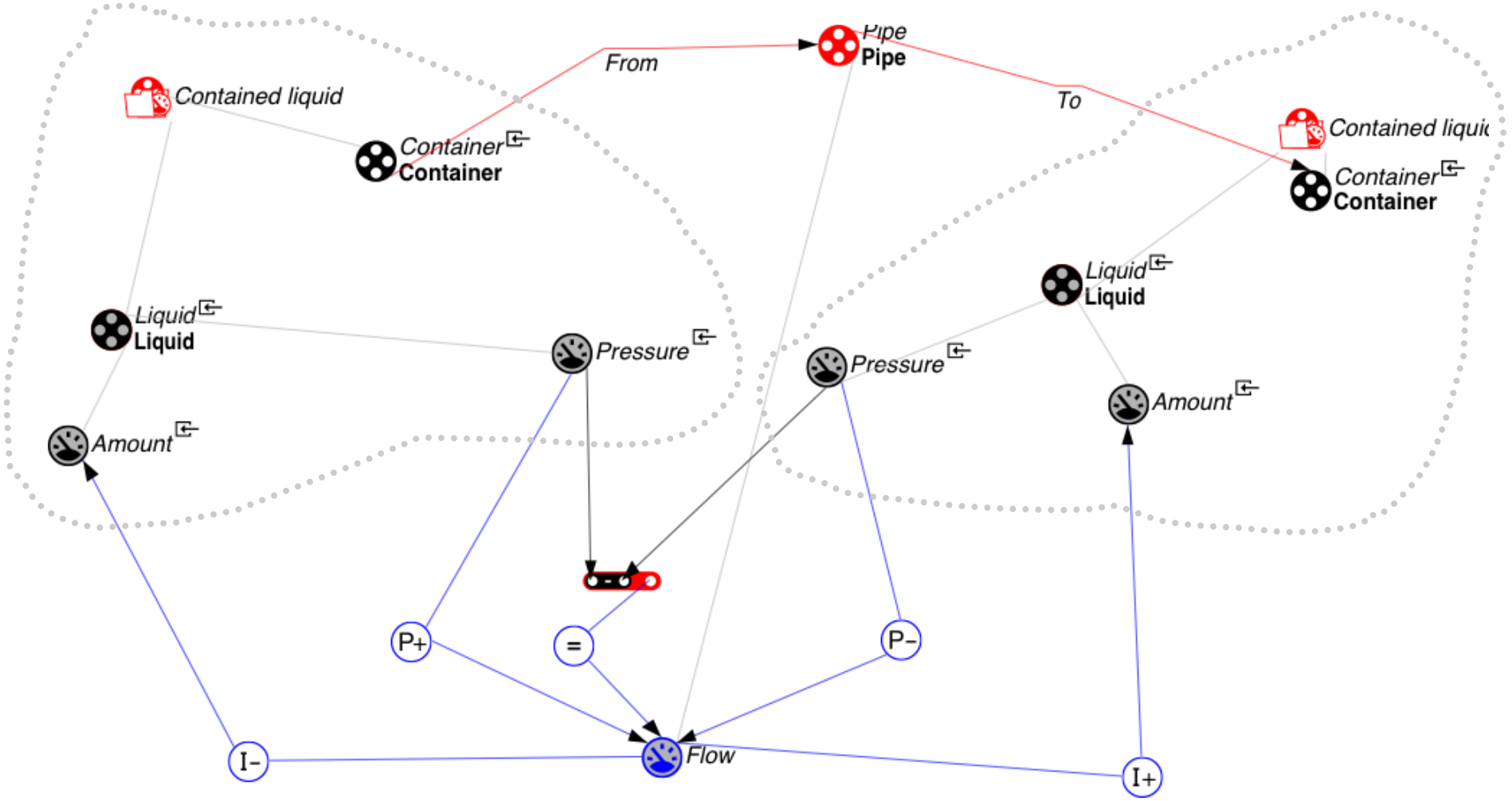


- $F = P_{LHS} - P_{RHS}$
- IF P_{RHS} <?,–/0/+> THEN F <?,+/0/–>
- IF P_{LHS} <?,–/0/+> THEN F <?,–/0/+>

Proportionality

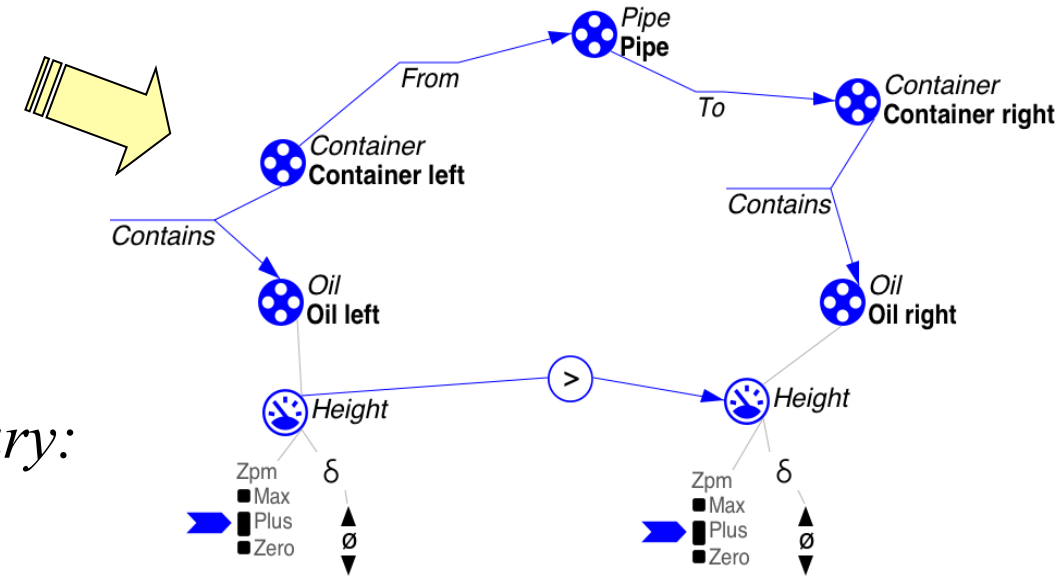
Influence

Process MF: Liquid flow

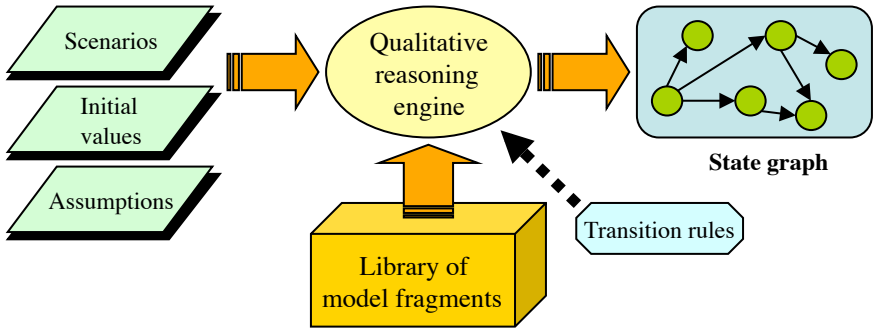


Simulating → State graph

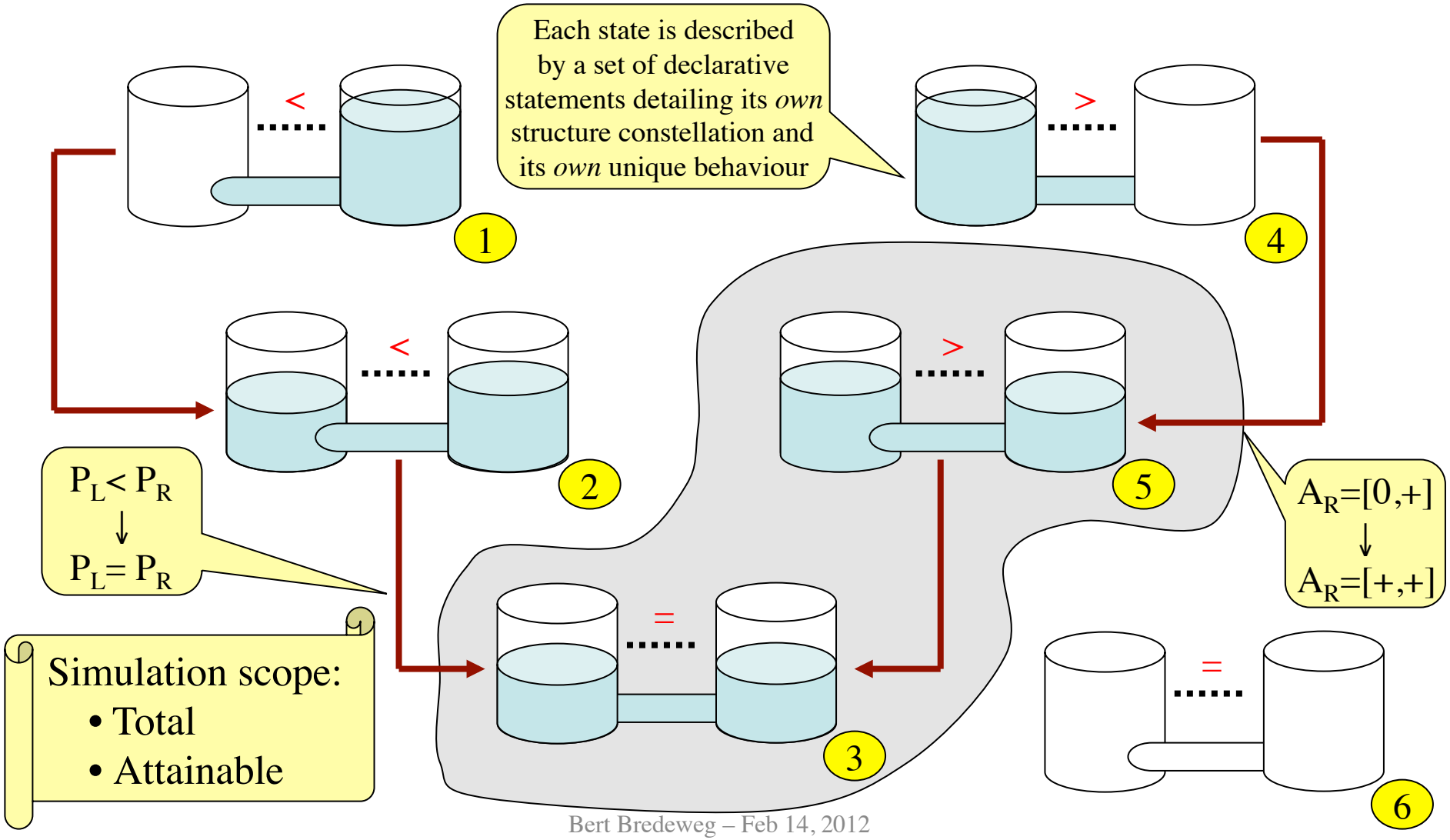
- Input
  - *Scenario*: a situational system description
  - *Model-fragments library*: domain knowledge



- Output
  - State-graph: representing possible behaviours



State-graph: System's behaviour



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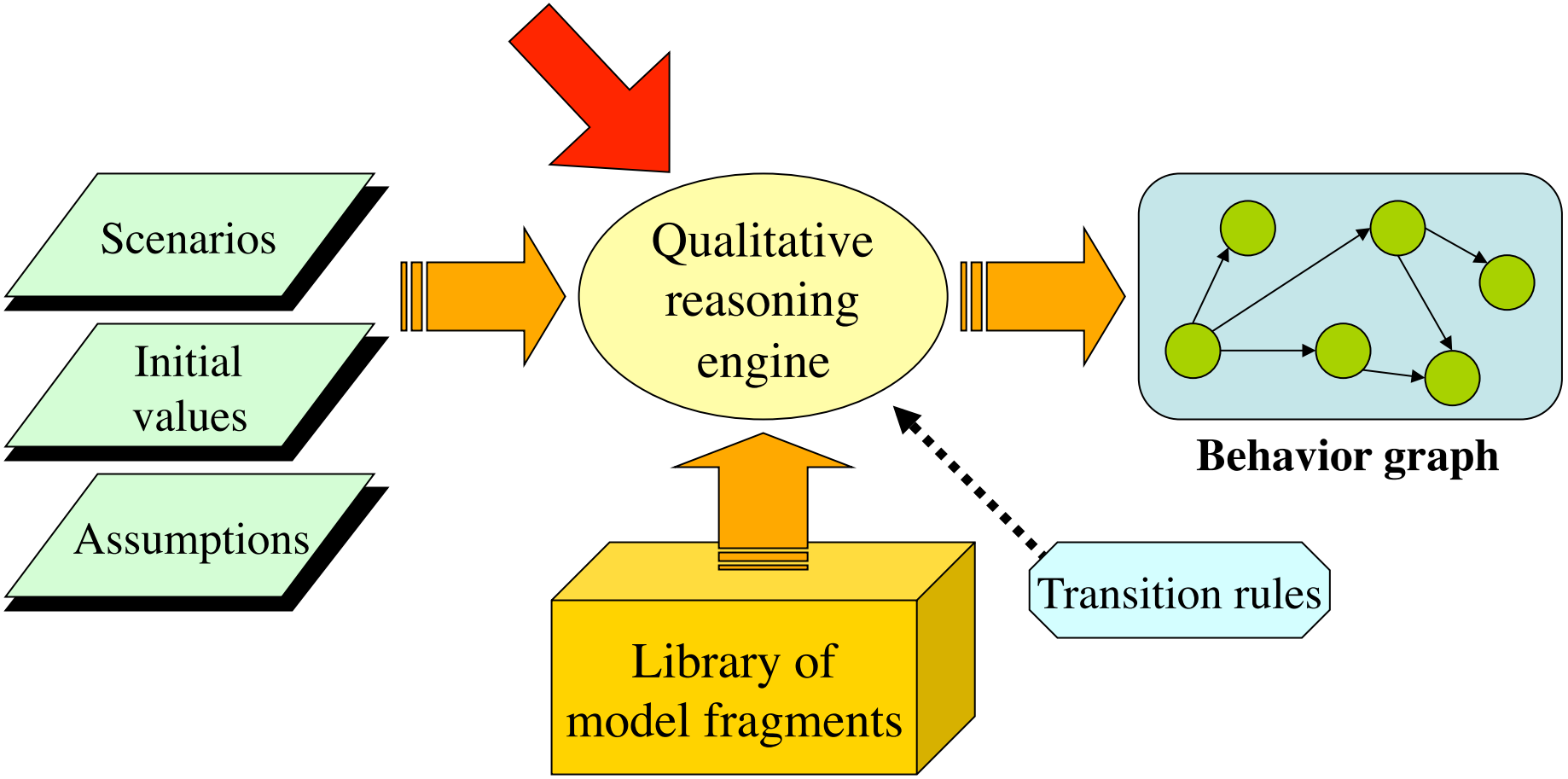
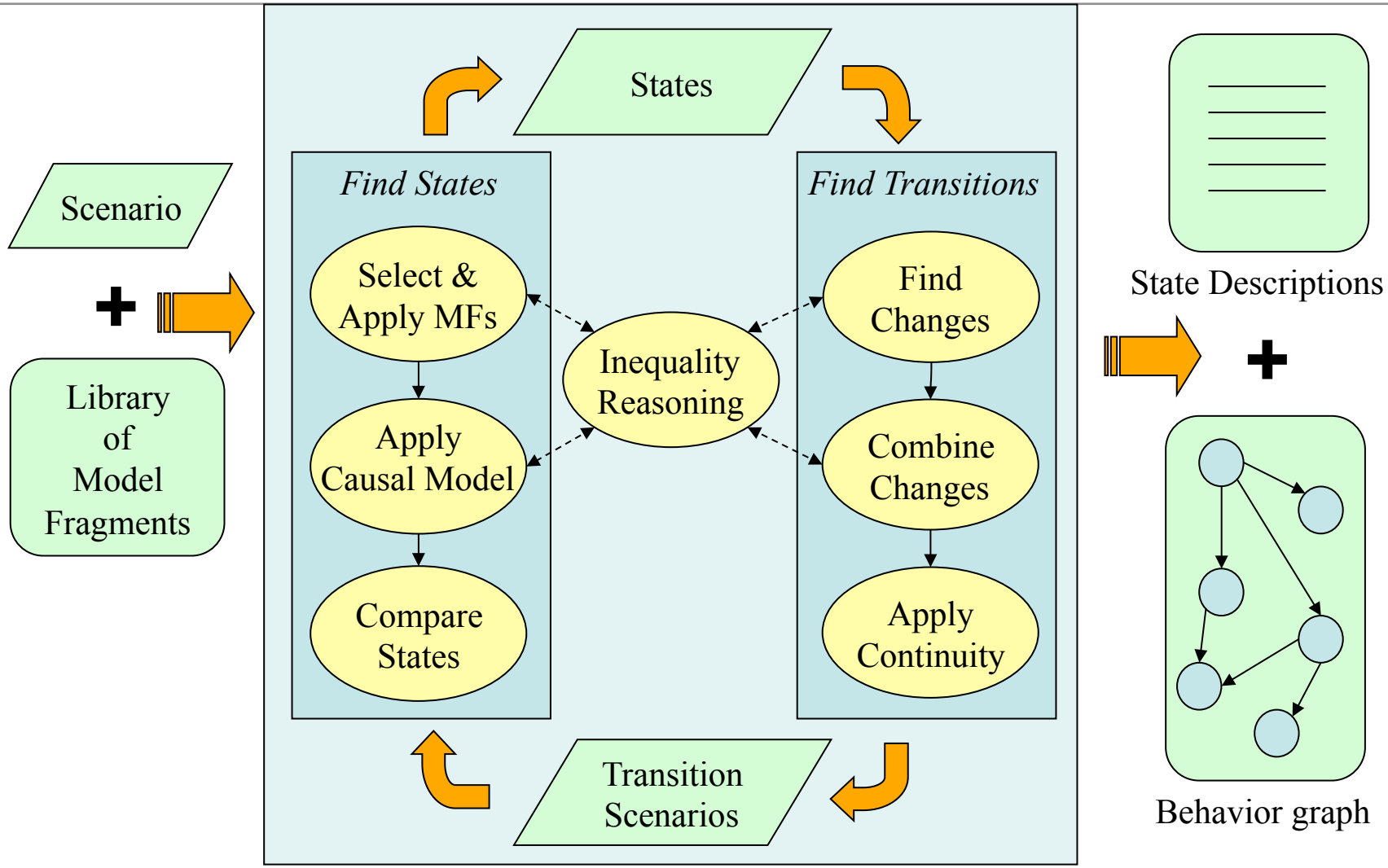
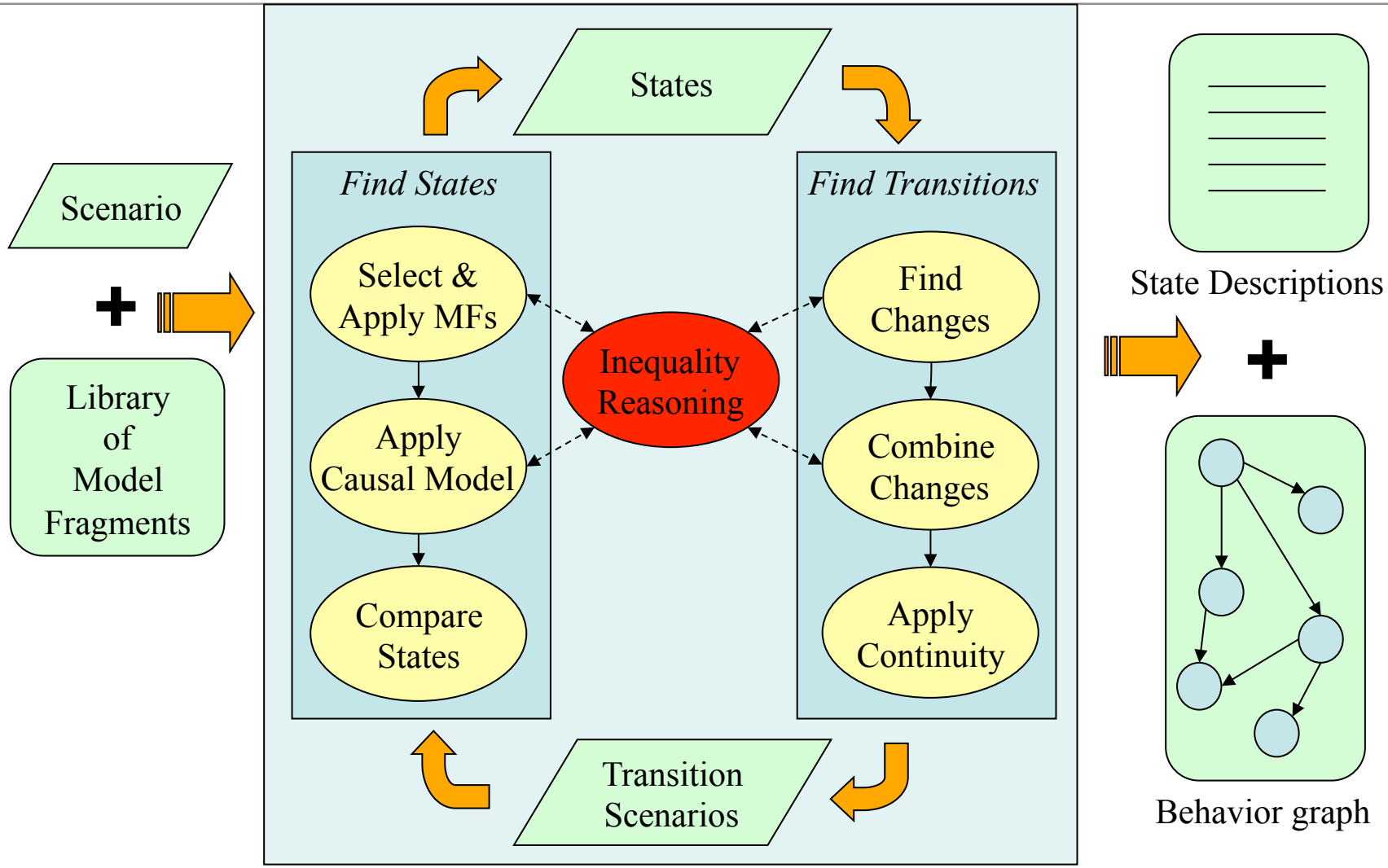
Qualitative Reasoning Engine



Garp3 - Reasoning Engine



Garp3 - Reasoning Engine



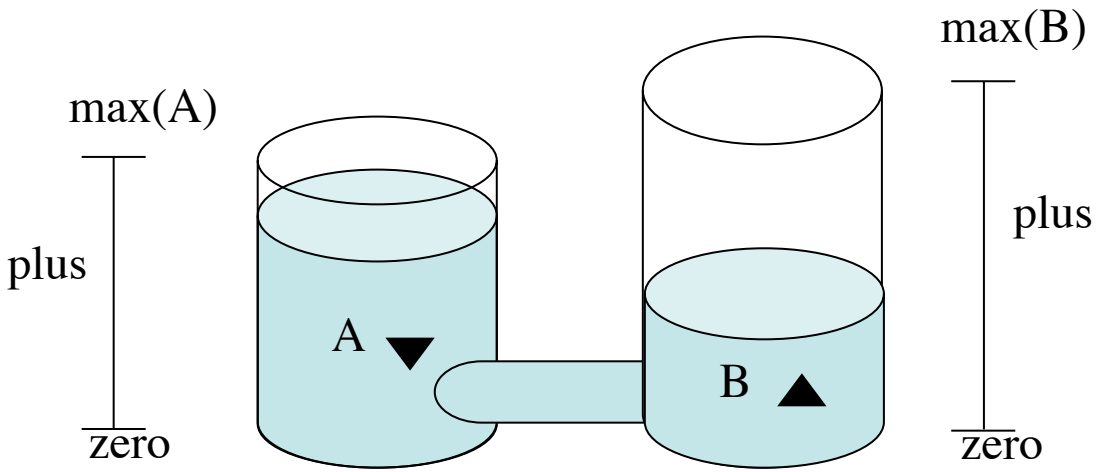
Dependencies: Inequality

< ≤ = ≥ >
(always w.r.t. a point)

- Between Magnitudes
  - A quantity and the value(s) from its Q-spaces
    - *E.g. temperature is at boil-point*
  - Magnitudes of two quantities
    - *E.g. temperature of substance A > Temperature substance B*
  - Values from the Q-spaces of two quantities
    - *E.g. boil-point water < boil-point of oil*
- Between Derivatives
  - A quantity and its derivative (values from its ∂q-space)
  - Derivatives of two quantities
  - Derivatives from the Q-spaces of two quantities

Example inequalities (U-tube)

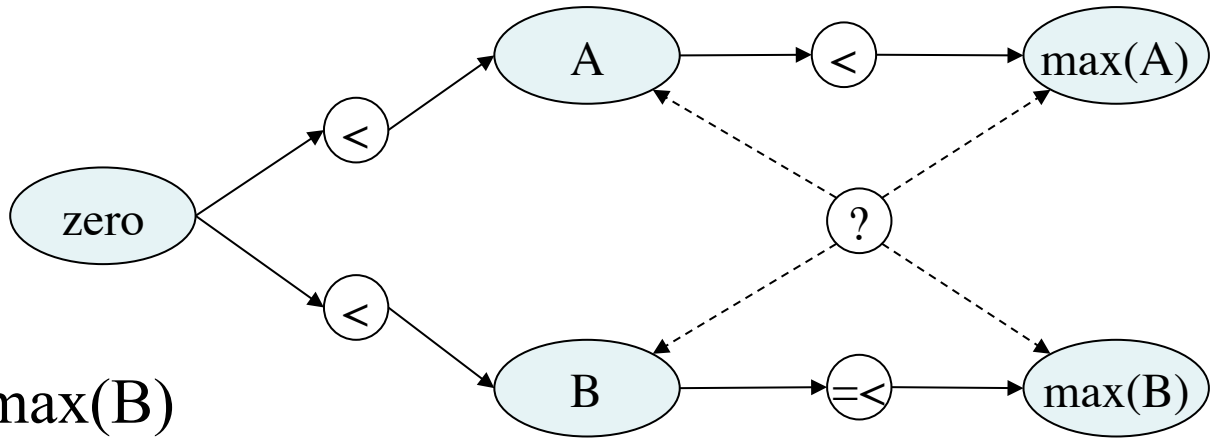
1. Quantity ↔ Quantity
2. Quantity ↔ Landmark
3. Landmark ↔ Landmark
4. Derivative ↔ Derivative
5. Derivative ↔ Zero



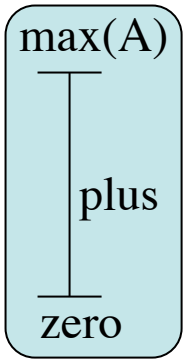
Inequality	Type
A > B	1
A > zero	2
B > zero	2
A < max(A)	2
B < max(B)	2
max(A) > max(B)	3
zero < max(A)	3
zero < max(B)	3
∂A < ∂B	4
∂A < zero	5

Example partial ordering

Not all details are always known…



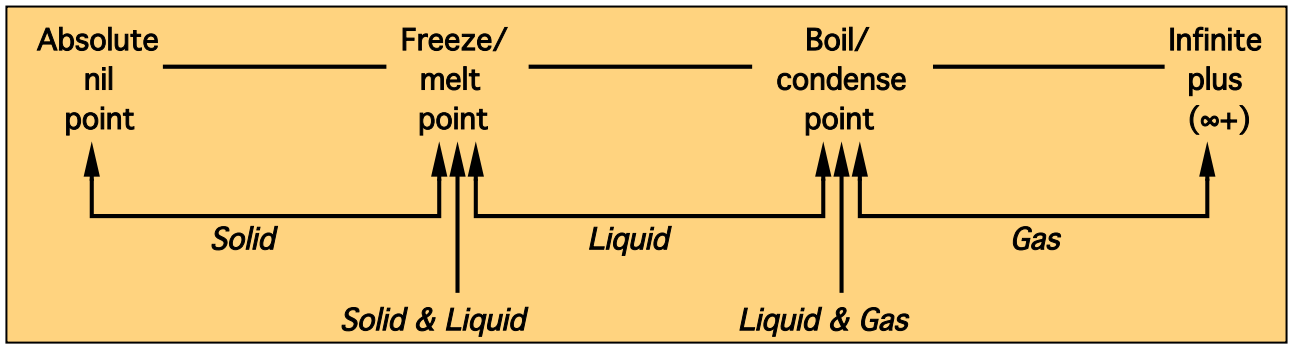
- Unknown
  - max(A) ? max(B)
  - A ? B
- Inferable:
  - zero < A < max(A) → A = ‘Plus’
  - zero < B ≤ max(B) → but precise value unknown

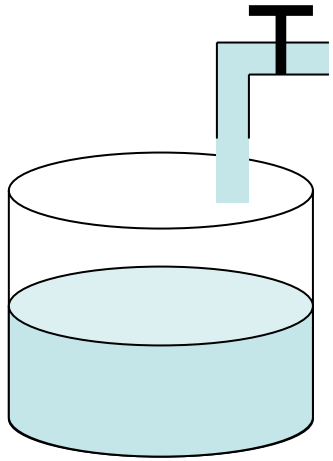


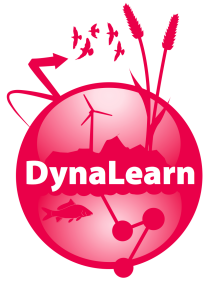
Quantity & Quantity spaces

- Changeable features of 'entities'
  - Entities: general name for objects / components
- Quantities have values:
  - Magnitude: e.g. {0, +, max}
  - Derivative: default: {-, 0, +}
- Values belong to a quantity space:
  - Ordered set of alternating points & intervals
  - Landmarks *(critical point values)*

e.g. Val_{Amount} = <+,+>







Optimise using Canonical forms

- Single form for

  $\{>, \geq, =, \leq, <\} \quad \Rightarrow \{>, \geq, =\}$

  $A - B = C \quad \Rightarrow A = B + C$

- Remove double:

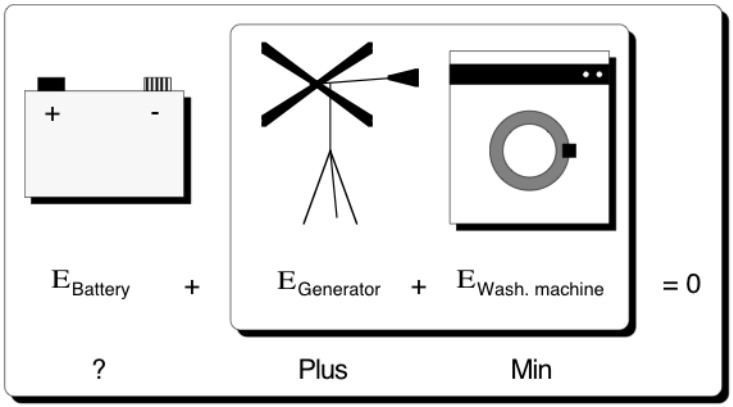
  $A = B \quad \& \quad B = A$

  $A + B > 0 \quad \& \quad 0 < B + A$

- Landmarks (Magnitudes) versus Derivatives
  - Independent groups
  - Single inference procedure

Inequality reasoning example (1)

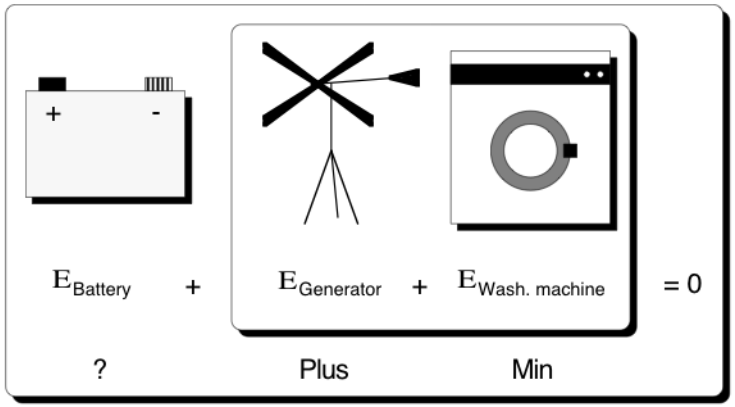
- Given:
  - $E_G + E_W < 0$
  - $E_B + E_G + Ew = 0$
- Asked:
  - E_B ?
- Ambiguous:
  - ? + Plus + Min = 0
  - E_B *can be any of* {Min, 0, Plus}



Calculus

Q2 \ Q1	+	0	-
+	+	+	?
0	+	0	-
-	?	-	-

Inequality reasoning example (2)



1. $E_B + E_G + Ew = 0$
2. $0 > E_G + E_W$
3. $E_B + \cancel{E_G + Ew} > \cancel{E_G + E_W}$
4. $E_B > 0$

General inference method for inequality reasoning (1)

- *Sum1* ***rel*** *Sum2*
  - *rel* {>, ≥, =}
  - *Sum* is addition of variables

- Basic algebraic simplification
  - $Sum1 + V \; \mathbf{rel} \; Sum2 + V \rightarrow Sum1 \; \mathbf{rel} \; Sum2$
- Anti-symmetry
  - $Sum1 \geq Sum2 \; \& \; Sum2 \geq Sum1 \rightarrow Sum1 = Sum2$
- Transitivity
  - See table…

General inference method for inequality reasoning (2)

Transitive inference rules

R1 & R2 →	A = B	A ≥ B	A > B
C = D	A + C = B + D	A + C ≥ B + D	A + C > B + D
C ≥ D	A + C ≥ B + D	A + C ≥ B + D	A + C > B + D
C > D	A + C > B + D	A + C > B + D	A + C > B + D

General inference method for inequality reasoning (3)

given: $A > B, B > C$

- *Transitivity*
  - $A > B \;\&\; B > C \rightarrow A + B > B + C$
- *Simplification*
  - $A + B > B + C \rightarrow A > C$
- *Result:* $A > C$

General inference method for inequality reasoning (4)

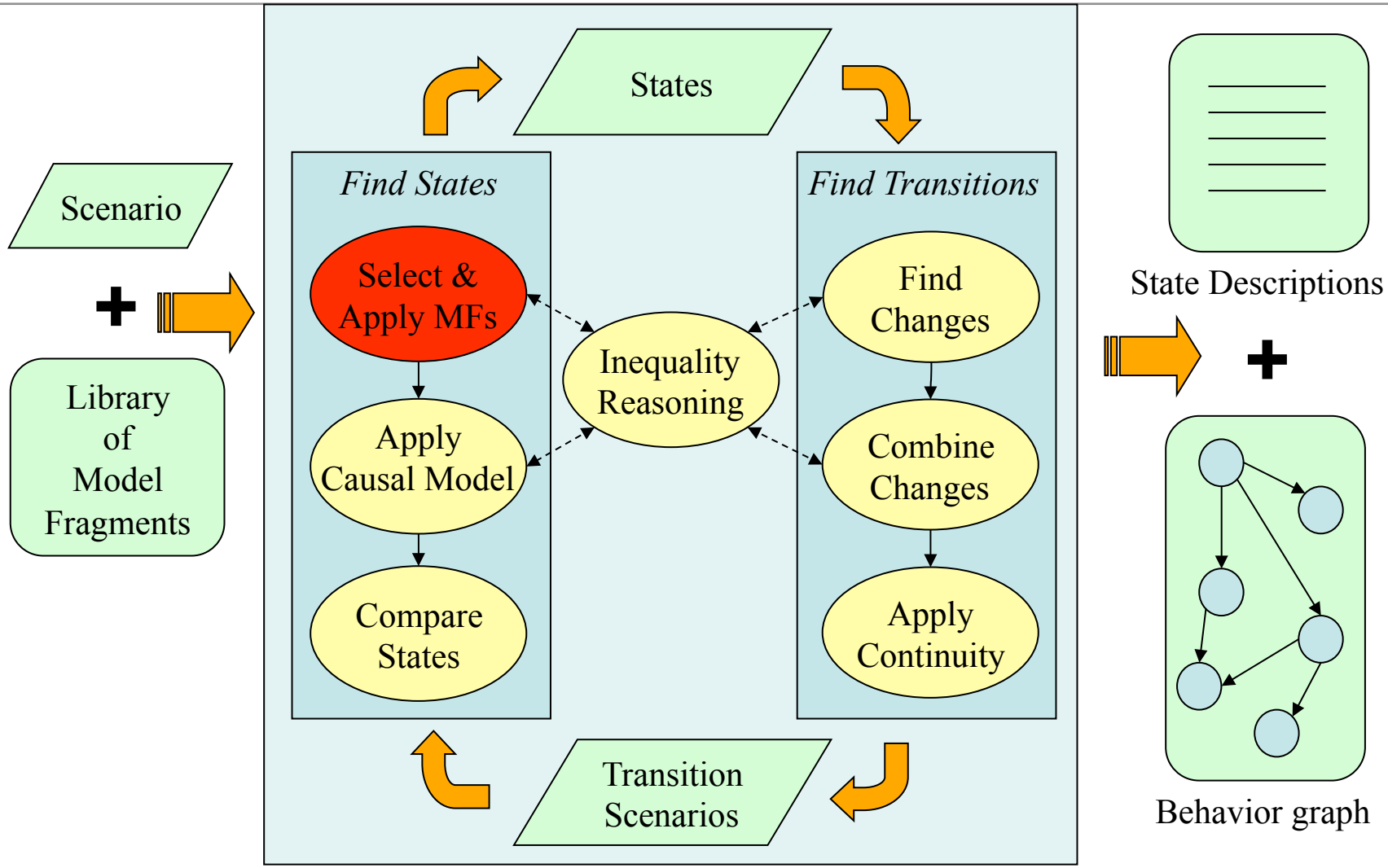
given: $P > Q$, $Q = P$

- *Transitivity*
  - $P > Q \;\&\; Q = P \rightarrow P + Q > P + Q$
- *Simplification*
  - $P + Q > P + Q \rightarrow 0 > 0$
- *Result: contradiction*

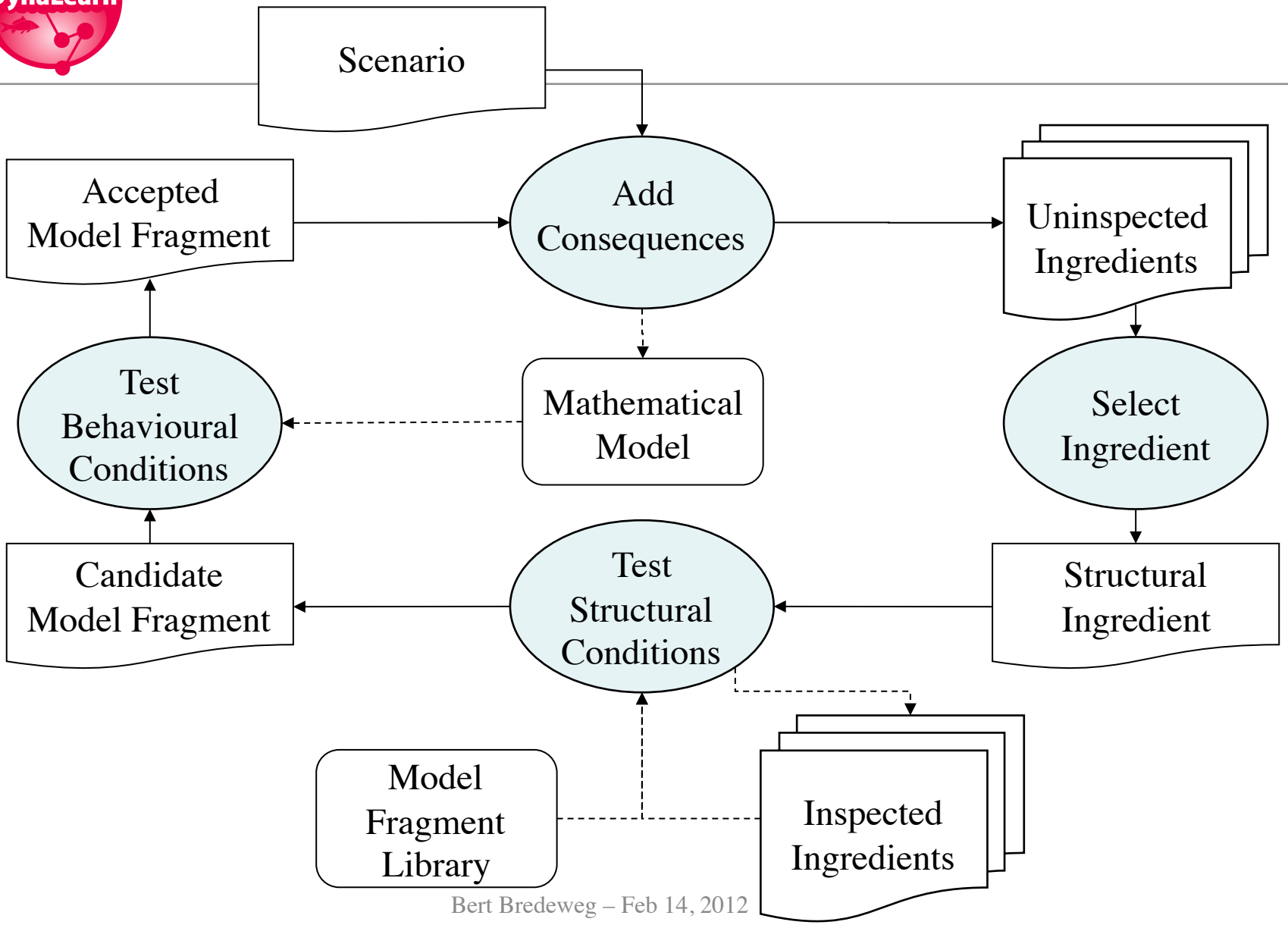
General inference method for inequality reasoning (5)

- Overall 3 possible outputs:
  - The input relation is a derivable relation:
    - it is already inferred or known.
  - The input relation causes a contradiction.
  - The input relation is added to mathematical model.
- Efficiency (heuristics)
  - Avoid non simplifiable irrelevant nodes !
  - Bitmaps
  - Restrict inference depth (optional)

Garp3 - Reasoning Engine



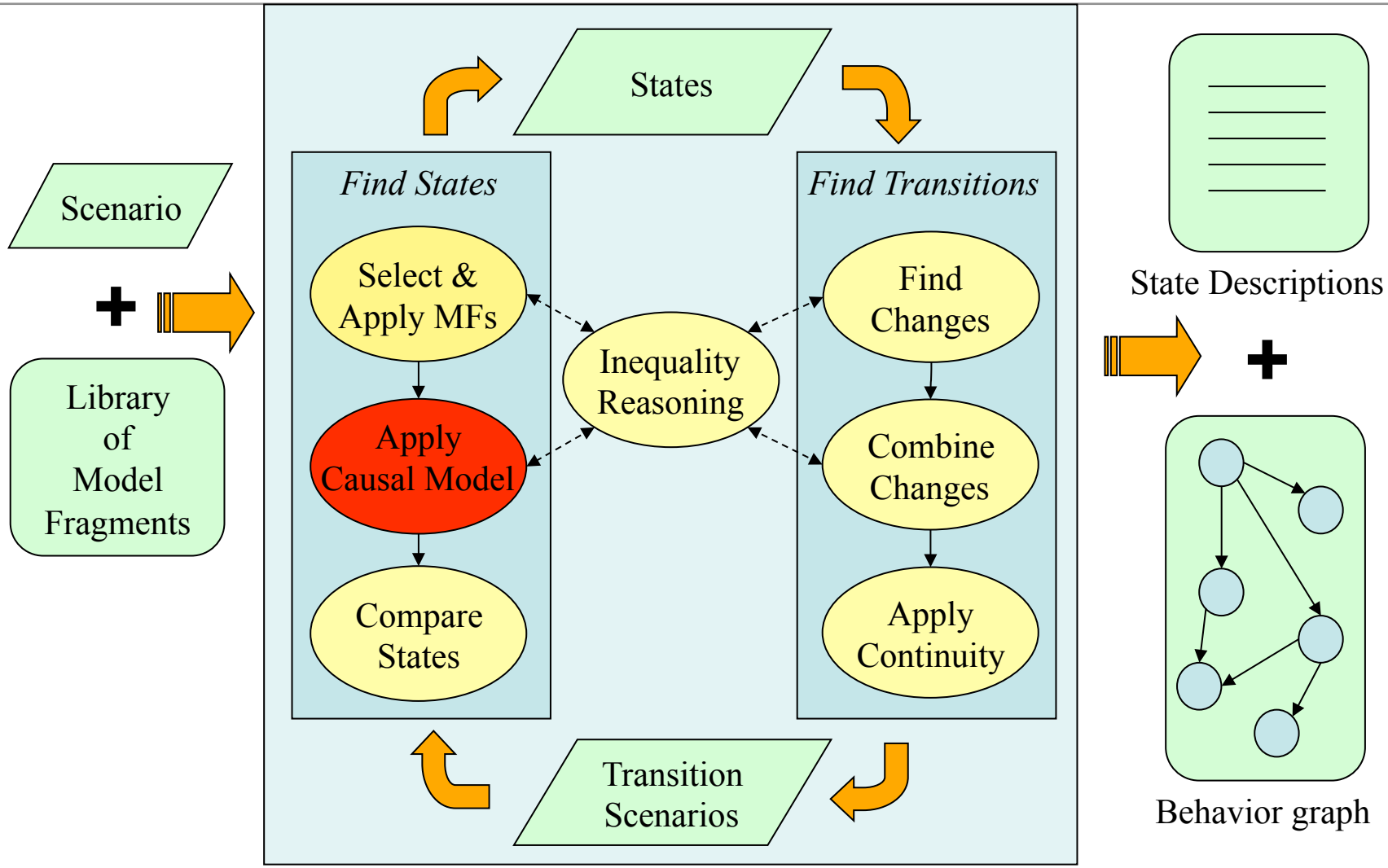
Model fragment selection



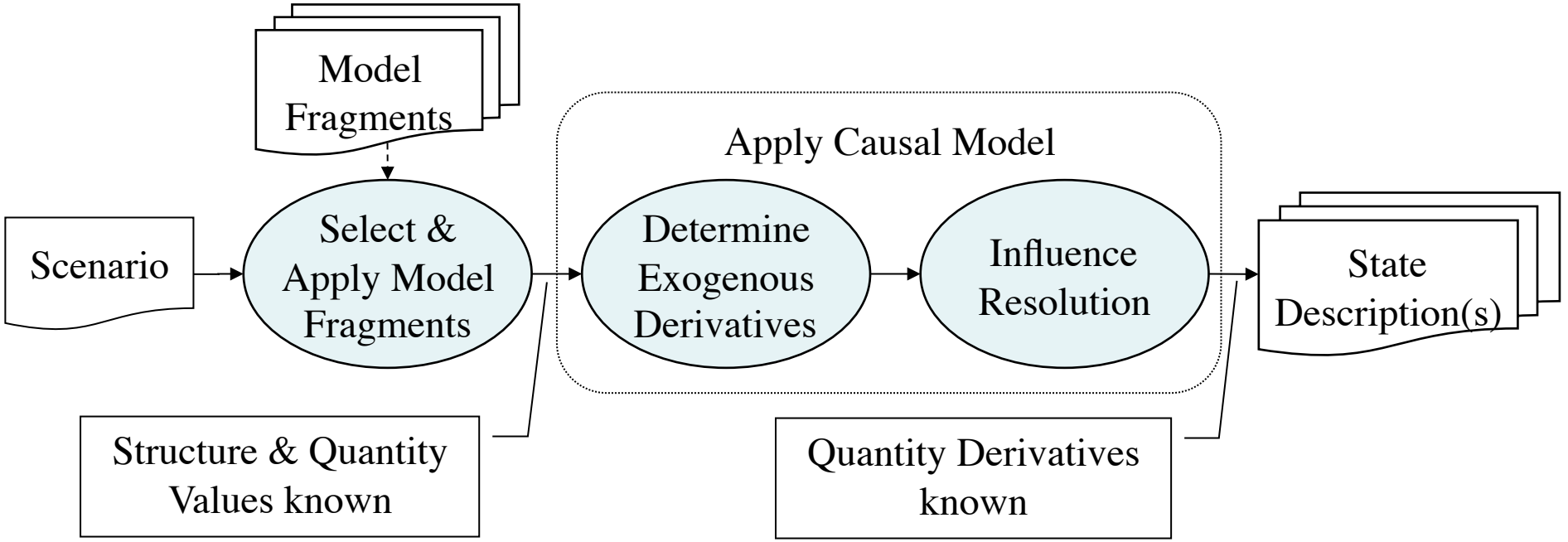
Model fragment selection: 3 possible outcomes

- If behavioural conditions known:
  - then the MF is accepted and its consequences are applied by the 'Add Consequences' inference.
- If behavioural conditions cause contradiction:
  - then the MF is rejected and not inspected anymore in this branch of the state search.
- If behavioural conditions not known nor contradictory:
  - then the MF is retested later to see if the behavioural conditions have become true.

Garp3 - Reasoning Engine



Determining state dynamics (derivatives)



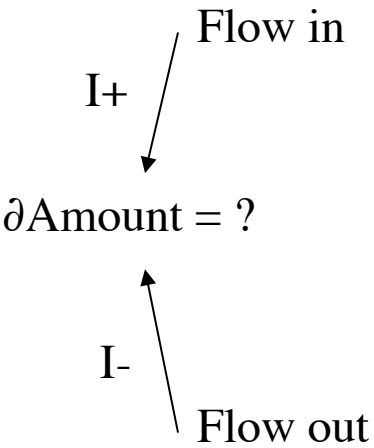
Causal dependencies: Influence

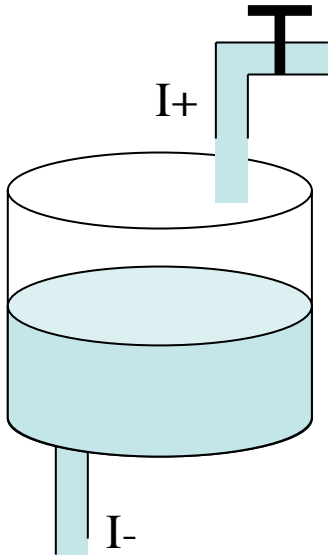
Requires advanced in/equality reasoning

- *Direct* influence: initial cause of change
- Positive (I+) or Negative (I-)
- Mag. of $Q_{influencing}$ determines the Der. of $Q_{affected}$

Calculus

Q2 \ Q1	+	0	-
+	+	+	?
0	+	0	-
-	?	-	-



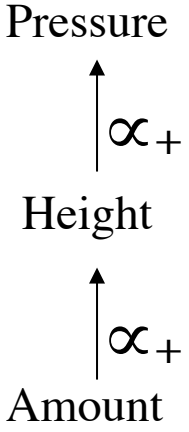


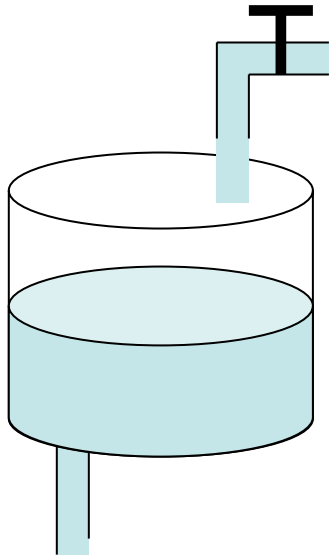
Causal dependencies: Proportionality

- *Indirect* influence: propagation of change
- Positive ($\propto+$) or Negative ($\propto-$) *(also known as P+ & P-)*
- Der. of $Q_{influencing}$ determines the Der. of $Q_{affected}$

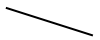
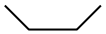
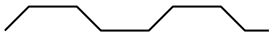
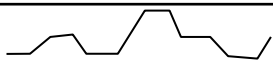
Calculus

Q2 \ Q1	+	0	-
+	+	+	?
0	+	0	-
-	?	-	-

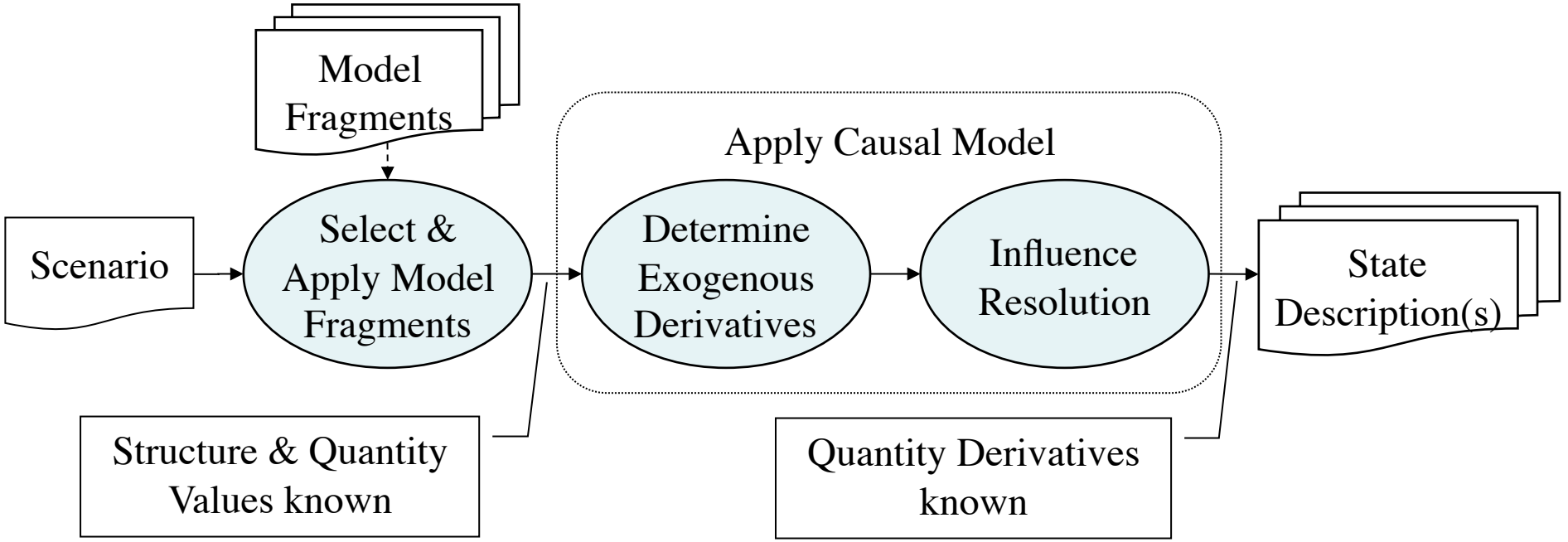




Exogenous quantity behaviour

Type	Description	
Steady	Derivative starts zero and remains zero.	
Increasing	Derivative starts plus and becomes zero in upper point of quantity space.	
Decreasing	Derivative starts min and becomes zero in lower point of quantity space.	
Parabola (positive)	Derivative starts plus, becomes zero in upper point of quantity space, then becomes min.	
Parabola (negative)	Derivative starts min, becomes steady in lower point of quantity space, then becomes plus.	
Sinusoidal	Derivative changes between min and plus in the extreme values of the quantity space, intermediately becoming zero in these extremes.	
Random	Derivative may change freely within continuity regime.	

Determining state dynamics (derivatives)

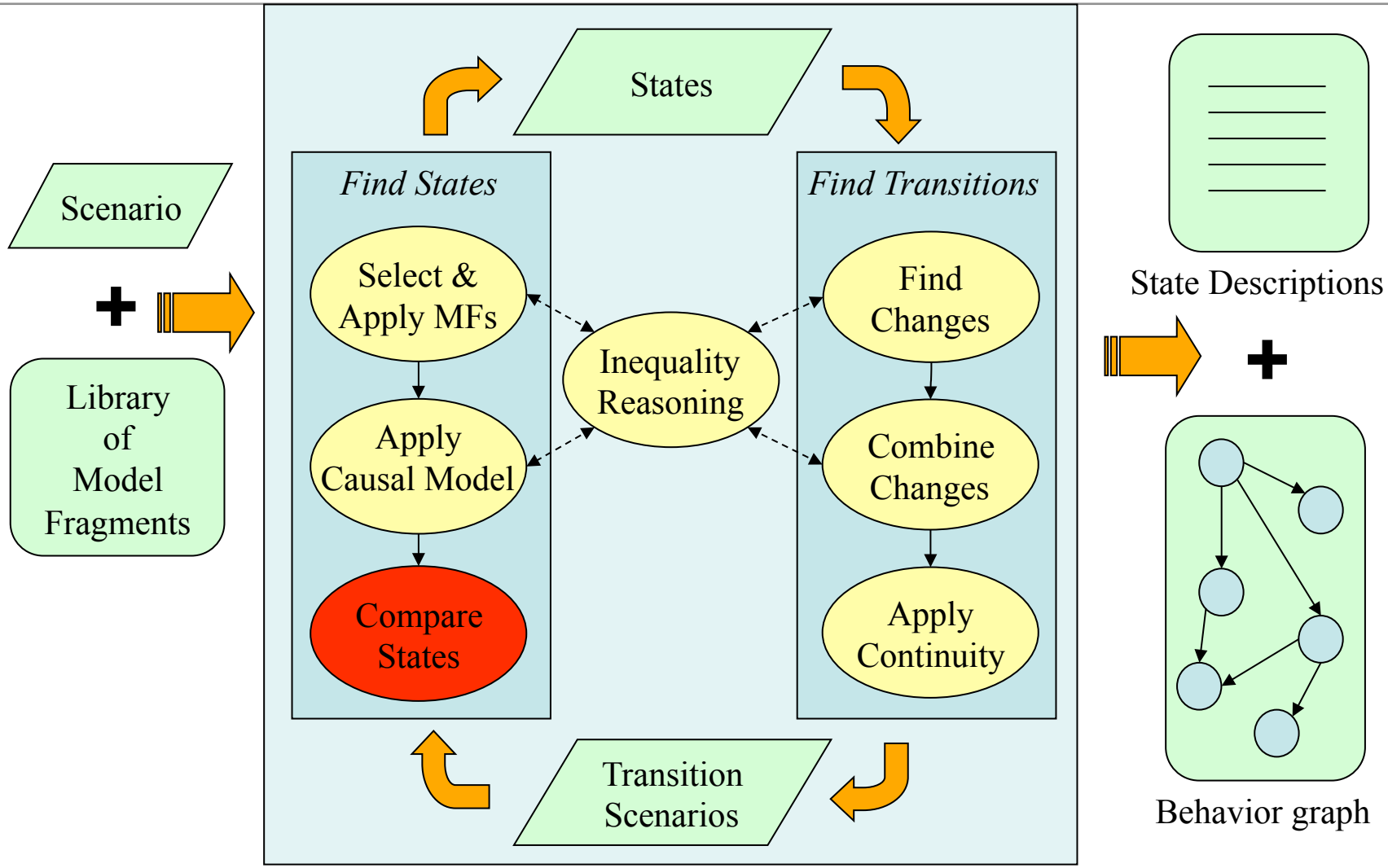


Influence resolution

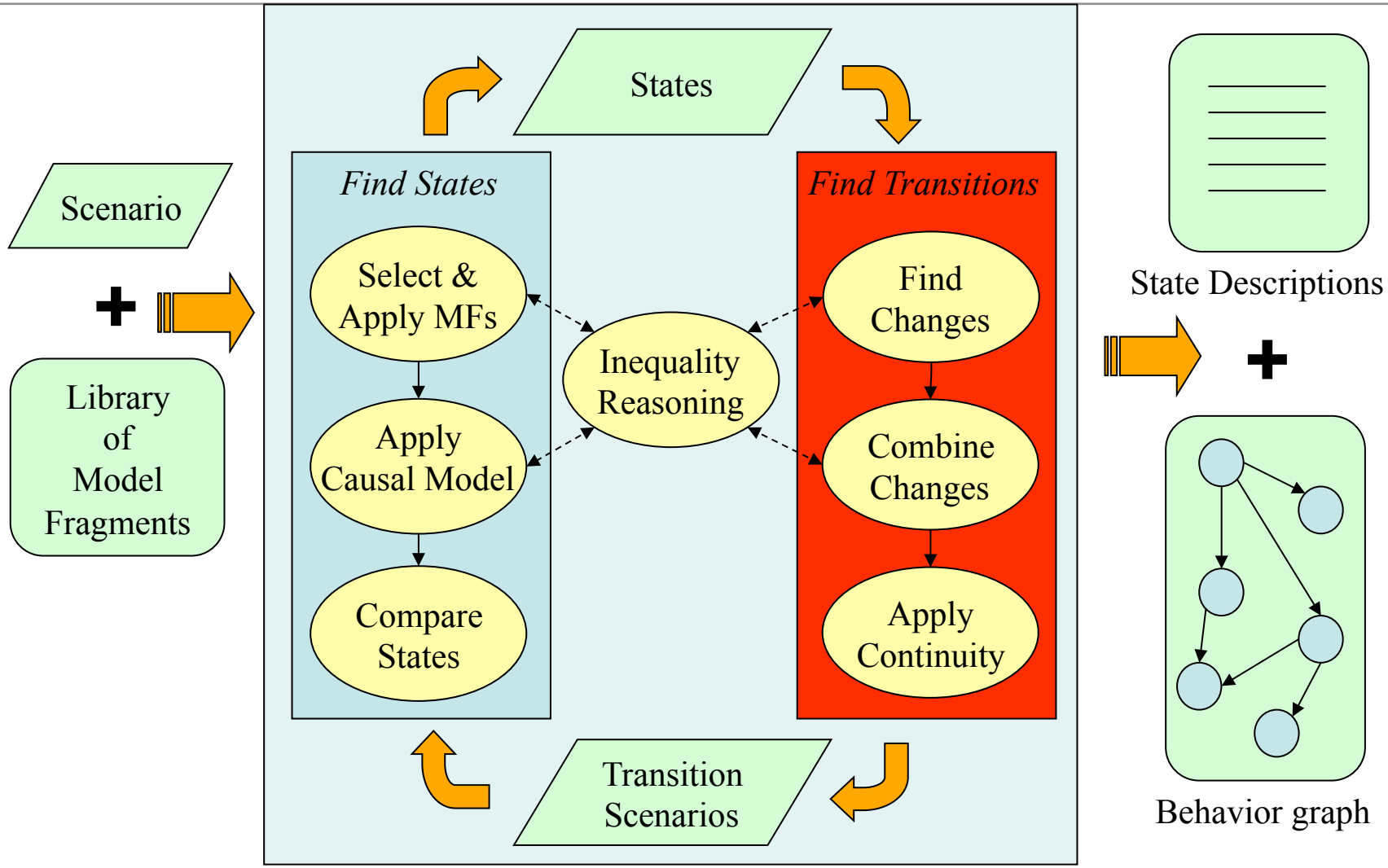
- $\sum$ I+ *rel* $\sum$ I-
- *rel* {>, ≥, =, ≤, <, *or ?*}
- Influence balance
  - Weigh the sum of positive influences against the sum of negative influences

- Same for: $\sum$ *P*+ *rel* $\sum$ *P*-

Garp3 - Reasoning Engine

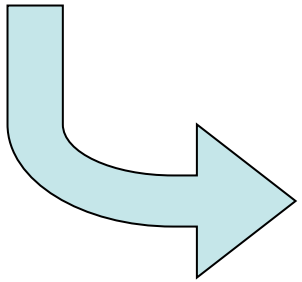


Garp3 - Reasoning Engine



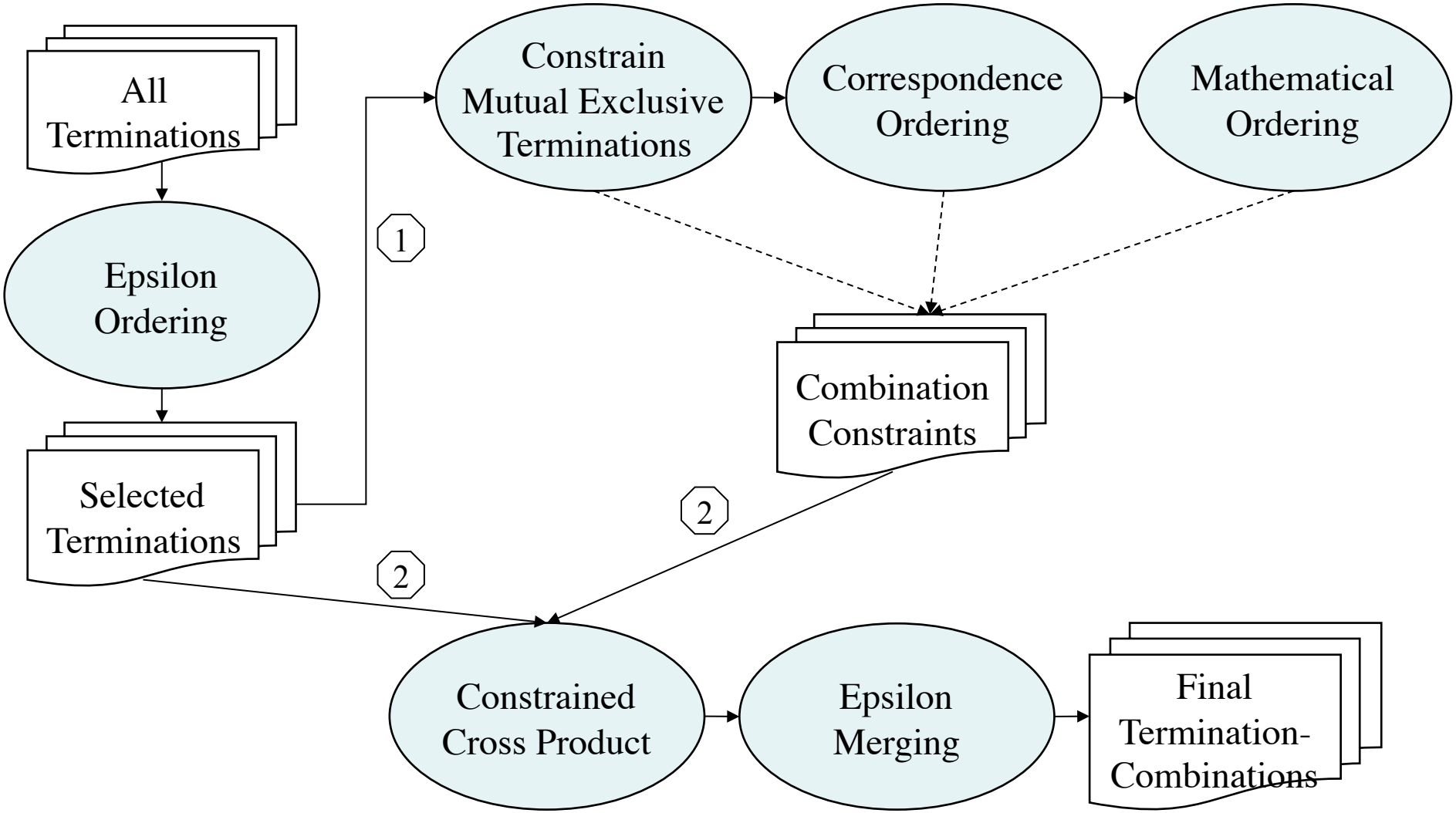
4 types of terminations

- Value terminations
- Inequality terminations
- Exogenous terminations
- Derivative terminations



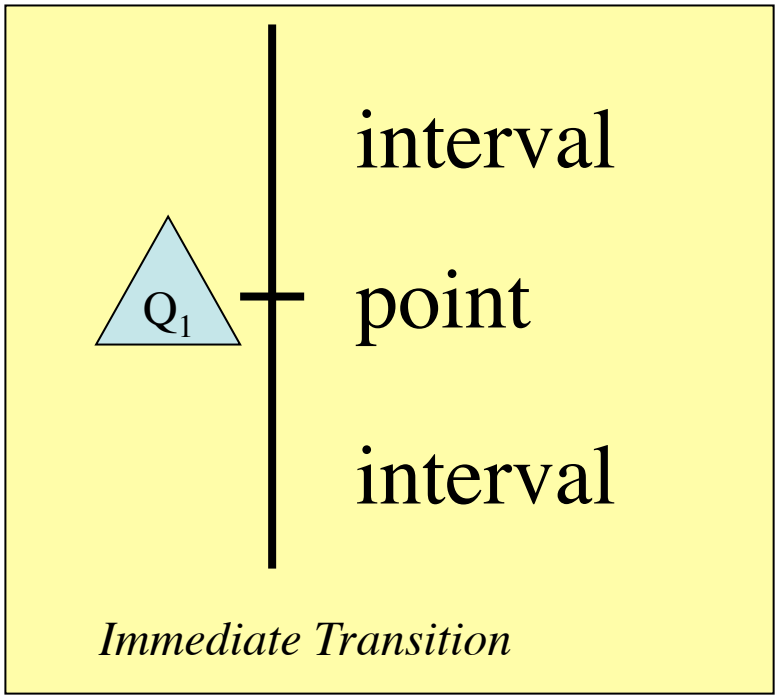
Derivative / 2nd order Derivative	$\partial(X) > 0$	$\partial(X) = 0$	$\partial(X) < 0$
$\partial'(X) > 0$		1: $\partial(X) > 0$	4: $\partial(X) = 0$
$\partial'(X) \geq 0$		*	*
$\partial'(X) = 0$			
$\partial'(X) \leq 0$	*	*	
$\partial'(X) < 0$	3: $\partial(X) = 0$	2: $\partial(X) < 0$	

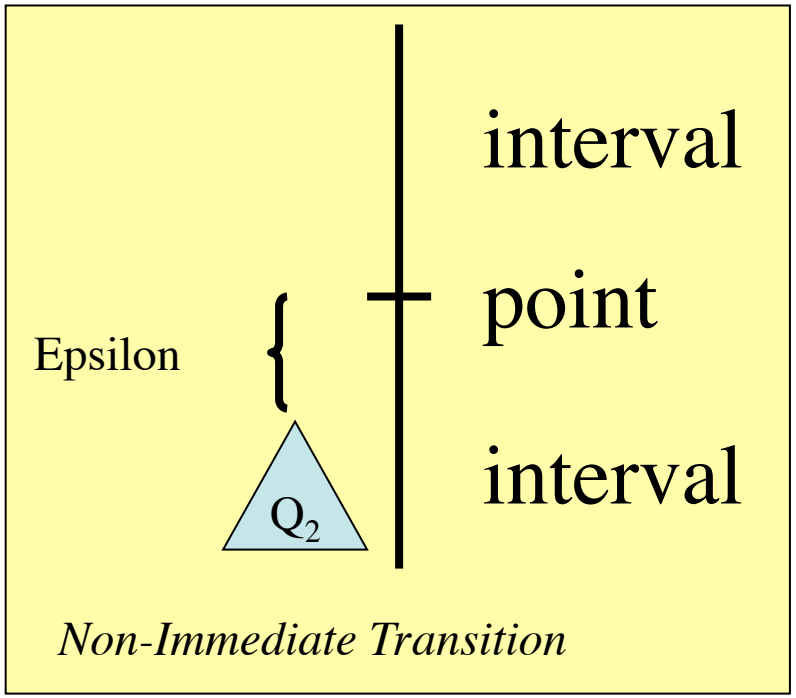
Find state transitions



Epsilon concept

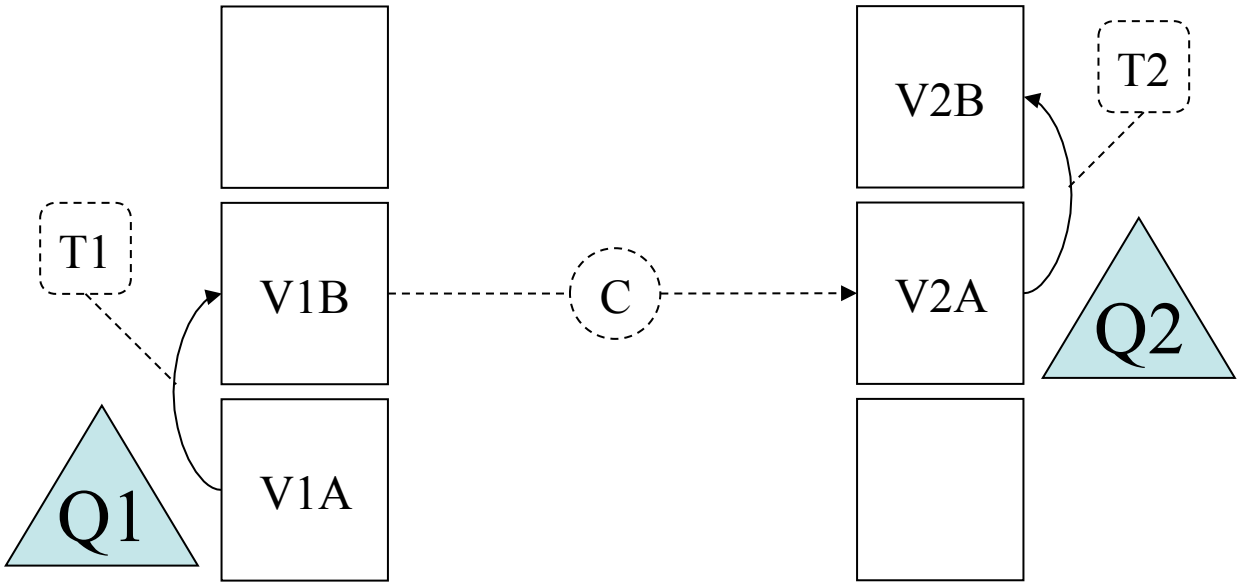
- Q_1 is increasing & on point (immediate)
- Q_2 increasing & in interval (non-immediate)





Correspondence ordering (1)

- T1 cannot co-occur together with T2
- Separately the terminations are both valid

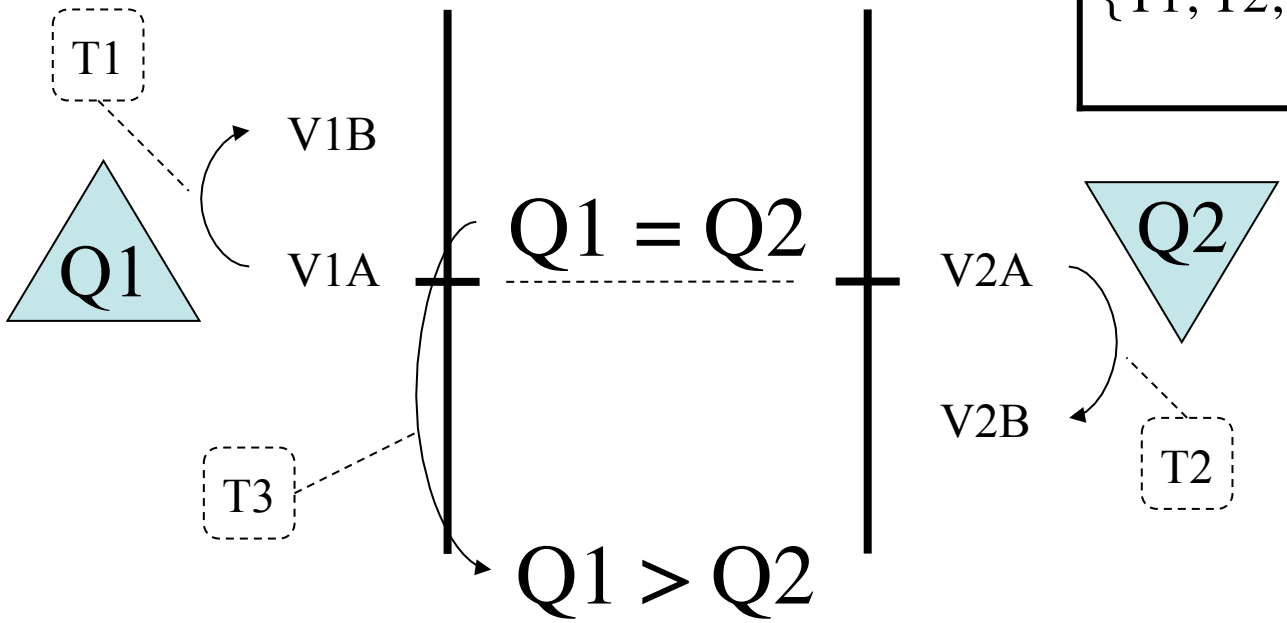


Correspondence ordering (2)

Nr.	Description	Term. Present	Corr. Involved	Valid	Invalid	Comment
1	Possible Deactivation	T1, T2	V1A → V2A	{T1}, {T1, T2}	{T2}	Q1 may move individually, or in combination with Q2.
2	Impossible Deactivation	T2	V1A → V2A		{T2}	T1 not present, remove T2.
3	Synchronous Activation	T1, T2	V1B → V2A	{T1}, {T2}	{T1, T2}	See text and Figure 6.1.2-4.
4	Asynchronous Activation	T1, T2	V1B → V2B	{T2}, {T1, T2}	{T1}	Q2 may move individually, or in combination with Q1.
5	Impossible Activation	T1	V1B → X		{T1}	T2 may be present but not relevant, remove T1.

Mathematical ordering

Valid	Invalid
{T1, T3}	{T1}
{T2, T3}	{T2}
{T1, T2, T3}	{T3}
	{T1, T2}



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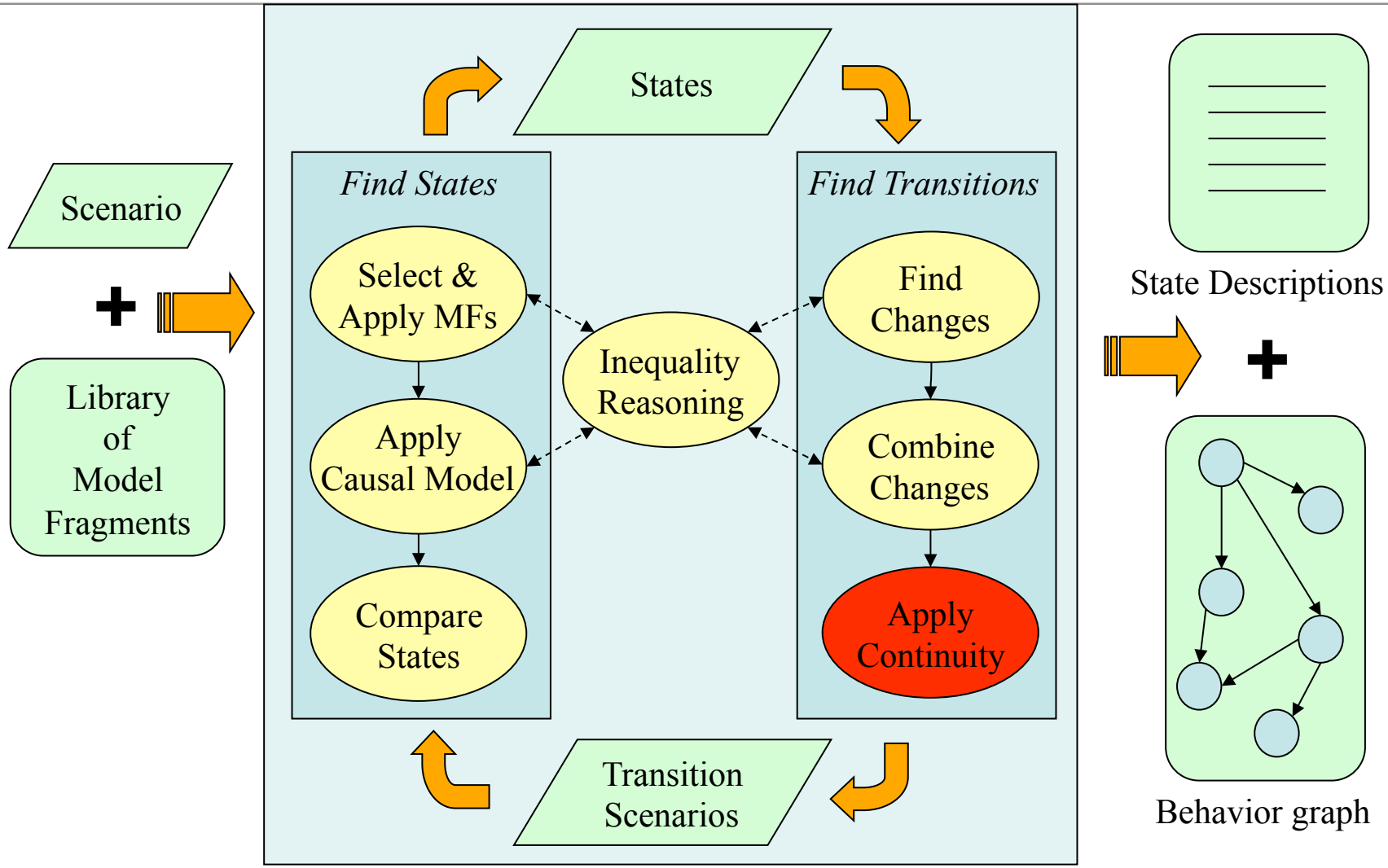


Continuity Rules

- $\delta Q = \text{Min} \Rightarrow \delta Q \leq \text{Zero}$
- $\delta Q = \text{Zero} \Rightarrow$ *None*
- $\delta Q = \text{Plus} \Rightarrow \delta Q \geq \text{Zero}$

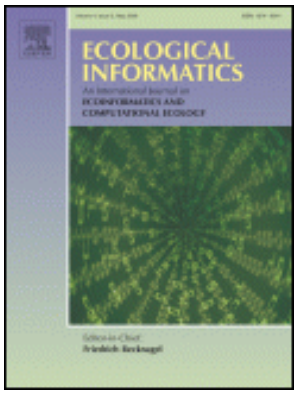
Latest improvements

- Multiplication
- Higher order derivative functionality
  - 2nd order (fine-tuned)
  - 3rd order (newly added)
- Comparative Analysis

Advanced models

- Ecological informatics, 4(5-6), 2009
  - Special issue

http://www.garp3.org

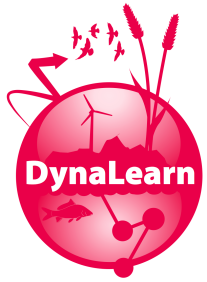


Overview

- Problem statement and Context
- Qualitative Reasoning
  - Example
  - Inequality reasoning
  - Causal model (directions of change)
  - Finding & Ordering terminations
- Further main ideas from DynaLearn
- Concluding remarks

Further main ideas..

- Progressive learning spaces
- Building explanatory models
- Grounding and recommendations
- Diagnosing simulation results
- Virtual characters (for motivation)
- Learner modelling (Bayesian network)
- Question gereneration & Dialogue
- Educational embedding



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http://www.DynaLearn.eu

Concluding remarks

- DynaLearn develops tools to facilitate educational research, with four key aspects:
  - Workspace for constructing conceptual knowledge
    - To day we focussed on the QR engine
  - Intelligent feedback for reflective thought
  - Induce motivation using virtual characters
  - Applied to (environmental) Science Education

Ultimate research question:
Under which conditions will learners be more motivated and achieve more?

Sabbatical Acknowledgement